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Evaluation of Retro-Reflective Beads in Airport Pavement Markings

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16. Abstract

This report identifies the results of a 1-year comparative evaluation on the use of retro-reflective glass beads in airport surface pavement markings. Glass beads meeting Federal Specification TT-B-1325B, Type I and III were tested at three airports for retro-reflectivity, effects on runway friction, conspicuity, and durability. The three test airports were Atlantic City, Greater Pittsburgh, and Phoenix Sky Harbor International airports. Data from this study show the use of beaded materials in airport markings increased the conspicuity and quality of the airport markings. Also discovered in this evaluation was the friction enhancement gained from the incorporation of beads and silica additives into the paint materials. As a result of the findings of this study, certain modifications are recommended for the two existing specifications regarding airport pavement markings, AC 150/5370-10A, Standards for Specifying Construction on Airports and AC 150/5340-1G Standards for Airport Markings.

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PREFACE

The author wishes to acknowledge all those who contributed to this report - directly and indirectly. Specific thanks are due to the management and personnel of the Atlantic City International Airport, Greater Pittsburgh International Airport, and the Phoenix Sky Harbor International Airport for their assistance during the testing.

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EXECUTIVE SUMMARY

Airport pavement markings are an important component of ground visual aids for pilots. These visual aids provide essential information to pilots, facilitating their tasks of taking off, landing, and maneuvering the aircraft on the airport surfaces. A common complaint by pilots is that airport pavement markings are not conspicuous. To enhance the conspicuity of the pavement markings some airports add retro-reflective glass beads to their pavement markings.

This report identifies the results of a one-year comparative evaluation on the use of retro-reflective glass beads in airport surface pavement markings. Glass beads meeting Federal Specification TT-B-1325B, Type I and III, gradation A, were tested at three airports for retro-reflectivity, effects on runway friction, conspicuity, and durability. After the testing began Federal Specification TT-B-1325B was updated to version C. The primary change in the specification was the elimination of the largest seive size of Type III beads. By eliminating the largest beads from that catagory the Type III beads should become slightly more durable than the previous specification Type III beads, however, they still remain much larger than Type I beads and are more subject to traffic wear and snow plow damage.

The three test airports, chosen for their various climatic conditions, were Atlantic City, Greater Pittsburgh, and Pnoenix Sky Harbor International airports. Data from this study show the use of beaded materials in airport markings increase the conspicuity and quality of the airport markings. Also discovered in this evaluation was the friction enhancement gained from the incorporation of glass beads and silica additives into the paint materials. As a result of the findings of this study certain modifications are recommended for the two existing specifications regarding airport pavement markings, AC 150/5370-10A, Standards for Specifying Construction on Airports and AC 150/5340-1G Standards for Airport Markings.

1. INTRODUCTION.

Airport pavement markings are an important component of ground visual aids for pilots. A common complaint by pilots is that airport pavement markings are not conspicuous. This problem is often seen as a failure to repaint, but the solution involves much more than frequent repainting. It is an involved and expensive task to repaint markings. Consequently, durability and conspicuity of markings may be viewed as a single problem in efforts to improve airport ground safety.

In 1992, the FAA Technical Center initiated a project to improve the quality of airport pavement markings and to determine environmentally acceptable alternative marking materials. This project included studying the use of two types of glass beads (Type I and III) to reflectorize the markings. Specifications for glass beads are detailed in Federal Specification TT-B-1325B, "Beads (Glass Spheres) Retro-Reflective".[1] After the testing began Federal Specification TT-B-1325B was updated to version C. The primary change in the specification was the elimination of the largest seive size of Type III beads. By eliminating the largest beads from that catagory the Type III beads should become slightly more durable than the previous specification Type III beads; however, they still remain much larger than Type I beads and are more subject to traffic wear and snow plow damage.

The project involved identifying the most promising products and techniques available for airport pavement markings. The selected materials included two epoxies, two water-borne paints, and one methacrylic resin. Field testing of these materials was conducted over a 1-year period. A number of airports were considered as test sites. The selected test sites, chosen for their various climatic conditions, included Atlantic City, Greater Pittsburgh, and Phoenix Sky Harbor International airports. Each of the five selected test materials were applied with and without glass beads at the selected airports during May and June 1993. Data were gathered periodically on their long-term performance. All testing was completed by June, 1994.

This report will address only the results and conclusions of the retro-reflective bead study and not the results of the alternative pavement marking materials. For further infromation on the study of the alternative pavement marking materials refer to the Federal Aviation Administration Technical Center report entitled Evaluation of Alterantive Pavement Marking Materials for Airports, DOT/FAA/CT-94/119.

2. RETRO-REFLECTIVE GLASS BEADS.

2.1 PURPOSE OF THE STUDY.

This study was conducted in response to a request from the Office of Airport Safety and Standards (AAS-100) to examine the retro-reflectorization of runway and taxiway markings. This study focuses primarily on the use of glass beads to add conspicuity to airport pavement markings along with consideration of the effects on runway friction with and without beads and/or a silica additive.

2.2 OBJECTIVES.

This study was directed specifically toward determining the operational benefits gained in using reflective glass beads in airport pavement markings. This was achieved through the completion of the following objectives.

- Determine retro-reflectivity of the two types of reflective glass beads over a one-year period.
- Determine the effects on runway friction when glass beads are applied to paint markings.
- Compare Type I and III beads for conspicuity as viewed from the cockpit of various type aircraft.
- Determine durability of the two types of reflective glass beads in an airport environment.

2.3 BACKGROUND.

Airport markings are discussed in a number of Government documents. Markings specifically required on airports are detailed in the Federal Aviation Administration (FAA) Advisory Circular (AC) 150/5340-1G, Marking of Paved Areas on Airports.[2] Striping material requirements for construction on airports are detailed in AC 150/5370-10, Standards for Specifying Construction of Airports.[3]

When airport markings are to be reflectorized, glass beads are generally used to impart retro-reflectivity. The beads are generally post applied into the wet marking paint at the rate of about 10 lbs. of beads per gallon of paint.

The various types of glass beads are broken down into grades by their Index of Refraction (IOR). The index of refraction is a scale index of the rate at which a material refracts light towards the source. The index correlates with the quality of the focal properties of the material used to refract the light. Characteristics of the beads that can change the IOR are the size, density, and roundness of the beaded material.

Two types of beads are detailed in the specification, Type I (1.5 IOR) and Type III (1.9 IOR). Type I beads are made from scrap glass and have a smaller gradation allowing more of the bead to submerge into the wet paint film. This allows the beads to withstand more abrasion and for the submerged beads to become exposed as the paint wears away. Type III beads are manufactured spheres of a higher-density glass. This higher density gives the bead a higher index of refraction and more accurately bends the incoming light ray to the center of the bead. The light ray will then be reflected back toward the surface of the bead very close to the initial entry point. This more accurate bending of the incoming light is what gives the Type III bead a more concentrated reflected beam than the Type I bead. Refer to figure A-1 for a depiction of the light reflecting characteristics of the two types of beads.

Currently, the Type I beads are used on roadway markings, and the higher refraction Type III are used on airport markings. The Type I beads are about one-sixth the price of the Type III beads ($0.25 vs. $1.65 per lb.) and by volume weigh about one-half that of the more expensive ones. Use of Type I beads on roadway markings provide improved reflectivity at reduced cost. Use of Type III beads on airports provides maximum reflectivity, but at a higher cost. Since the current specification (AC 150/5370-10A) does not require the installation of glass beads, the airport sponsor may decide whether or not to install them. In actual practice, highways tend to have higher quality pavement markings than airports due to their use of beaded paint.

The U.S. military services have experienced similar choices in their programs for periodic runway and taxiway striping. In recent years they have conducted a number of research efforts to improve materials for marking airports. As one example, the U.S. Air Force recently changed their practice to allow the use of Type I (1.5 IOR) beads on the markings for taxiways and aprons on military airfields.[4] While their runway striping is still accomplished using the Type III (1.9 IOR) beads, studies are being conducted to determine if the less expensive beads could also be employed in this application.

3. GENERAL FRAMEWORK FOR TESTING.

3.1 SELECTED TEST MATERIALS.

Table 1 contains the selected marking materials. Each material manufacturer applied their own material at the various airport test sites. The various materials in this table will be referenced throughout the report.

TABLE 1. TEST MATERIALS

TYPE MATERIAL	MANUFACTURER/MATERIAL
Water-borne Paint	Rohm and Haas(water-borne#1) Morton Duroline 2000(water-borne#2)
Two-Part Epoxy	ADI/Safeway, Inc.(epoxy#1) Poly-Carb, Inc.'s Mark-55(epoxy#2)
Methacrylic Resin	Morton Dura-Stripe

3.2 TEST CONFIGURATION.

Basic test marking configurations were developed to display both marking colors and types of beads. Six test stripes of each test material, each 6 inches x 8 feet were applied at selected taxiway locations on each of the test airports. Test stripes were painted in yellow (3) and white (3). One stripe of each color was non-beaded, one beaded with 1.5 IOR beads, and one beaded with 1.9 IOR beads. Each configuration was arranged in the same manner so as to provide consistent displays at each of the selected airports. Atlantic City and Phoenix each have both concrete and asphalt taxiway surfaces and at these two locations taxiway test beds were installed on both surfaces. Refer to figure A-2 for a depiction of the taxiway test stripes.

In addition to the taxiway test stripes, selected runway centerline stripes (3 feet x 120 feet) were installed at each of the test airports. The runway stripe installations involved replacing the existing runway centerline stripes with the test materials. Seven runway stripes were repainted at Atlantic City International Airport and Greater Pittsburgh International Airport. Four stripes were repainted at Phoenix Sky Harbor Airport. Reference figures A-3 through A-8 for specific locations and layouts for each airport.

The seven Atlantic City and Pittsburgh runway centerline test stripes consisted of a stripe of each of the five test materials and two additional stripes of the methacrylic resin, one with 1.5 IOR traffic marking beads and one with the airport 1.9 IOR beads. These extra two stripes were added to determine the relative effectiveness of each type of bead. In addition, the Atlantic City site included two threshold stripes of water-borne paint, one with 1.5 IOR beads and the other with 1.9 IOR beads to accomodate in-flight evaluations. The relative long-term

effectiveness of each type of bead was analyzed during the course of the evaluation.

3.3 APPLICATION SCHEDULE.

Application of materials was accomplished at each of the three airports in accordance with the preplanned schedule and was completed during May and June 1993. Each application was accomplished as planned with the exception of the Phoenix location, where only four of the five planned runway stripes were applied. This exception was due to a misplaced shipment of materials for the (epoxy#1) product which would have been the fifth test material. The materials did reach the test site the following day for inclusion in the taxiway test installation.

3.4 SURFACE PREPARATION.

At all test locations, the surfaces were prepared in advance of the application of the marking materials. This was necessary to insure a clean surface for maximum adhesion. At Atlantic City and Phoenix a combination of sandblasting and surface grinding was used to prepare the surfaces. At Pittsburgh, hydroblasting was used for preparation of the runway and taxiway surfaces. It was noted that hydroblasting and sandblasting were effective means of removing oil and fuel residue as well as concrete curing compounds on new pavement surfaces. It was also noted that the only successful means of <u>totally</u> removing multi-layered paint was by grinding the paint off the surface. However, this technique did result in some slight pavement damage.

3.5 DRAWDOWNS.

Each subcontractor provided a drawdown (sample) of the materials applied on the day of installation at each airport location. The material was applied to a thin piece of aluminum during the taxiway test stripe installation. Each drawdown was then marked to identify the manufacturer and material name. The drawdowns were used as a baseline for comparison with field test specimens over the 1-year time frame.

3.6 SCHEDULE FOR REVIEW AND ANALYSIS.

Periodic visits were conducted at each airport to review the test materials for conspicuity, durability, and rubber buildup. The glass beads were inspected for friction, reflectance, and retention in the various test materials. Monthly visits were accomplished at the Atlantic City International Airport. Quarterly visits were accomplished at the Pittsburgh and Phoenix airports.

3.7 MEASUREMENT OF RETRO-REFLECTIVITY.

Field measurement of retro-reflectivity involved the use of the portable Mirolux Retro-reflectometer device that can be taken into the field to conduct measurements. This device measures retro-reflectivity of airport and highway markings in millicandelas. Use of these devices provide objective performance data for research purposes. A Mirolux retro-reflectometer was obtained from the U.S. Air Force and used during each inspection to determine the reflectivity of the test markings on a real-time basis. Initial and quarterly readings were obtained and recorded on worksheets.

3.8 FRICTION.

Friction testing was conducted at two of the three selected airports. The Atlantic City and Pittsburgh airports had the friction testing equipment on site to collect the skid resistance data necessary for this test. The device used at both airports was the K.J. Law Runway Friction Tester (RFT). Data were collected initially upon application and on a quarterly basis thereafter.

4. RESULTS.

Initial evaluation of the test materials commenced shortly after installation at each of the test sites. Visual observations were made, retro-reflectivity was measured, and friction readings were obtained.

Periodic examinations of the test markings have resulted in significant data accumulation. Friction testing of the various materials was conducted at the Atlantic City and Pittsburgh airports. In addition, special airborne evaluations of the threshold and centerline stripes with reflective beads were conducted at the Atlantic City International Airport to determine the variances in conspicuity between the two types of glass beads as well as the adjacent non-beaded stripes.

An early finding in the study was the benefit of including silica as a friction enhancer and also to reduce rubber adherance to the pavement markings. The silica appeared to cause the rubber to "flake" away and not smear onto the paint as was the case with the test stripes that did not have silica. There was a significant difference in rubber adherence between the epoxy runway test stripe with silica and the epoxy without silica along with the waterborne runway stripes with and without silica. In both cases the materials with silica retained their white color and did not get obscured by rubber. The addition of the silica to the test stripes was at the discretion of each of the manufacturers involved in the study.

4.1 REFLECTIVITY.

The taxiway test stripes were measured with a Mirolux retro-reflectometer device to determine baseline levels of retro-reflectivity. Refer to figures A-9 through A-40 for individual readings measured at each test location. Figures A-41 and A-42 show the operation of the Mirolux Retro-reflectometer. In addition, a demonstration of a mobile device (Laserlux) was conducted by its manufacturer to show its effectiveness and potential benefit. This vehicle uses a laser to sweep across a refectorized marking and record the reflectivity values into a computer. The demonstration of the Laserlux did provide a positive indication that a mobile retro-reflectometer is a practical application of new technology for rapidly evaluating large areas of pavement markings. The hand held Mirolux however, proved to be more practical for evaluating the smaller test markings of the taxiway test beds. Refer to figure A-43 for a depiction of the Laserlux.

Data concerning relative effectiveness of Type I (1.5 IOR) versus Type III (1.9 IOR) glass beads showed the benefits of each type. Initial Mirolux readings confirmed the higher reflectivity of the 1.9 IOR glass beads during the early period following application. Over time, a reduction occurred in retro-reflectivity of the 1.9 beaded materials while the 1.5 beaded

materials tended to sustain performance. At the completion of the one-year test period, all 1.5 beaded materials at the Atlantic City and Pittsburgh test sites had higher retro-reflectivity than their 1.9 counterparts.

Some of the degredation of the 1.9 bead can be attributed to snow plow strikes. The 1.9 bead has a larger diameter than the 1.5 bead allowing more of the bead to be exposed and subjected to traffic wear as well as being dislodged by snow plows. The 1.5 beads did not show the same effects. In Phoenix the glass beads were not exposed to snow plows but did show a decline in reflectivity. This decline was not as rapid at the Phoenix test site but was still apparent from the Mirolux readings.

The United States Air Force has conducted studies that also show initially higher retro-reflectivity readings after installation of the 1.9 bead, but experience significant decline over the longer term of one year.[5]

An advantage the Type I bead has over the Type III is that they are smaller spheres allowing more beads to be in place per square inch of the marking. Some of these spheres submerge into the paint and become exposed over time, allowing their reflectivity to remain at high levels. The smaller spheres also have approximately half the weight by volume of the 1.9 beads giving you approximately twice the number of reflective beads per pound.

An important finding in Phoenix was the enhancement the glass beads provided to the runway centerline stripes at night. Phoenix does not have runway centerline lighting and their runways are exposed to intense rubber buildup. During a nighttime inspection of the runway it was noted that the white paint of the centerline was totally obscured but due to the reflective beads the stripes were still visible. This finding proves the value of the reflective beads for increasing conspicuity of the markings, particularly on runways that do not have centerline lighting.

4.2 AIRBORNE EVALUATION.

Three nighttime test flights were accomplished at the Atlantic City test site. The flights were conducted using a Convair 580, Rockwell Aero Commander, and a Piper Arrow aircraft. The Aero Commander and the Arrow have landing lights on the nose gear in close proximity to the eye of the pilot whereas the Convair 580 landing lights are outboard on the wings. The location of the landing light is critical because the Type III bead has a narrower beam returning to the source light. This is caused by the higher density glass more accurately bending the incoming light and reflecting it back toward the surface of the bead very close to the initial entry point. The Type I bead, on the other hand, has a wider return beam because of the lower density glass not bending the light as accurately as the Type III bead. This makes the beaded stripes visible if the source light is not in close proximity to the pilot's eye.

A total of seventeen approaches to Atlantic City International's runway 31 were flown by the evaluation pilots during the course of the three test flights. On the first two flights using the Arrow and the Aero Commander, the observers agreed that the amount of light reflected back to the pilot from the left threshold stripe (1.9 bead) was approximately twice that of the right threshold stripe (1.5 bead). It was considered significant that the remaining unbeaded stripes were not visible at all to the pilots. It was also noted that the presence of runway centerline lights reduced the effectiveness of the reflectorized threshold markings. On the third flight using the Convair 580, the difference in conspicuity levels between the two threshold stripes had narrowed with both stripes being acquired visually at the same distance from theshold.

After the final approach of each of the three flight tests the aircraft was back taxied down the runway to the runway 31 threshold to determine how far away the stripes could be seen by the pilots. The 1.9 beaded stripe was visually acquired first in each case and at a horizontal distance of approximately 1000 feet. The 1.5 beaded stripe was acquired at a distance of approximately 500 feet in each case. On the third flight's back taxi both stripes were acquired simultaneously at a distance of 2000 feet from the higher cockpit of the Convair 580 aircraft. On all three tests the remaining unbeaded stripes were not acquired until the aircraft reached the immediate vicinity.

The two additional beaded runway centerline test stripes (#6 & #7) were also examined for subjective performance. It was noted that there was little observable difference between the two from the cockpit while passing one after the other and not viewing them side-by-side. There was a significant improvement in contrast and visibility of these stripes as compared with the remaining non-beaded centerline stripes.

4.3 FRICTION.

Friction testing was conducted at two of the three selected airports. The Atlantic City and Pittsburgh airports possessed the friction testing equipment to collect the skid resistance data necessary for this test. Data were collected initially upon application and quarterly using the RFT Friction Test vehicle. Refer to figure A-44 for a depiction of the vehicle in operation.

Friction data obtained from the various materials indicated that certain marking materials exhibit positive friction benefits as compared with others. A reduction in friction readings would indicate that the abrasiveness of the material had degraded. Refer to figures A-45 and A-46 for the materials tested and friction data for the Atlantic City and Pittsburgh airports. In general the friction readings for the two beaded stripes (#6 & #7) were equivalent or better than those for the unbeaded materials. At the Pittsburgh test site the ambient pavement

friction was determined to be 0.75 mu. The #6 and #7 stripes (with beads and silica) provided average friction readings of 0.55 and 0.56 mu, slightly lower than that of the unbeaded #5 stripe with the silica additive, but well above that of the older existing paint markings (0.2 mu) and the minimum maintenance level of 0.41 (at 60 mph) as specified in the FAA Advisory Circular 150/5320-12B, Measurement, Construction, and Maintenance of Skid-Resistant Airport Pavement Surfaces[6].

The use of additives such as silica and/or beads offers friction benefits as compared with unbeaded paint without silica. This correlates with similar results achieved with the Saab Friction Tester by personnel from the O'Hare Airport in Chicago on October 24, 1993, on beaded and non-beaded solvent base paint.[7]

4.4 SILICA ADDITIVES.

Throughout the one-year evaluation it became apparent that the use of silica as a dropped-on additive provided positive friction benefits on the runway and taxiway surface markings and served to resist rubberization. No specification for using silica in pavement markings currently exists. In order to establish a specification three criteria had to be determined. These are color, material size, and rate of application.

In determining the color requirement, the foremost characteristic is to enhance the base pigment. White silica composed of at least 99.5 percent silica with no significant oxide contamination appears to maintain the white coloration of the runway markings while not affecting the yellow characteristics of the taxiway stripes. Any silica of less than 99.5 percent purity will begin to discolor the striping.

For this test the materials had a silica additive with a gradation requirement in the 50/60 range. This gradation size was large enough to provide positive friction enhancement while still being small enough to allow for the proper application and adherence of beads and not effecting the overall reflectivity of the marking.

The third criteria is the application rate. The most desirable rate is two to four lbs. of silica per gallon of paint. This rate will achieve the same goals as the gradation size and the friction level is enhanced without jepordizing the reflectivity of the marking.

The above detailed criteria were determined from field testing and from information gathered from interviewing professionals from the striping and silica industries.

4.5 COST-BENEFIT ANALYSIS.

A cost comparison was made of purchasing and installing the various materials on a typical (10,000 ft.) airport runway. A number of sources were contacted regarding the actual costs for performing this type of work. Inputs from the manufacturers regarding the estimated cost for application of their products were also obtained. Since a variety of products, application rates, and cost variables were encountered, hypothetical parameters had to be established to provide "typical" costs for marking a runway. The selected criteria are outlined below:

• Runway Length:	10,000 Feet
• Runway Width:	200 Feet
• Type Markings:	Precision Markings - Both Ends
• Paint Coverage:	107 sq. feet/gallon
• Paint Cost:	$ Variable - $6.50 to $35 per gal.
• Type I Bead Cost:	$.25 per lb.
• Type III Bead Cost:	$1.65 per lb.
• Rate - Paint Application:	15 Mils/Wet
• Rate - Bead Application:	10 lbs. per gallon

Using the above criteria it was determined that 142,500 sq. ft. of painted area would be required on the runway. This would require 1332 gallons of paint. Labor costs were based on current government wage grade salaries involving a crew of 4 applying materials at the rate of 10,000 sq. feet per hour.

Labor costs are broken down as follows:

• Application (crew of 4):	10,000 sq. ft. per hour
• Labor hrs - 10,000 Runway:	14.25 crew hours
• Labor Rate:	$20.00 per hour/individual

Typical costs for painting a runway with an inexpensive water-borne material (cost $6.50 per gallon) with various types of reflective beads are broken down below:

• Painted Runway (No Beads)

8,658	Paint
1,138	Labor
$9,796	Total

• Painted Runway (Type I (1.5) Beads)

8,658	Paint
3,330	Beads
1,138	Labor
$13,126	Total

• Painted Runway (Type III (1.9) Beads)

8,658	Paint
21,978	Beads
1,138	Labor
$31,774	Total

It is noteworthy that the increased cost of the Type III beads exceeds the cost of the paint. It is significant also that the runway painting cost is more than doubled by use of the Type III beads. In effect two runways can be painted for the price of one if Type I beads were used for providing retro-reflectivity.

5. CONCLUSIONS.

The results of the testing indicate that the success of materials used in visual markings may be dependent to a significant degree on the operational and climatic environment. In certain environments, runway centerline markings may last only a few weeks before repainting is required. Certain materials do appear to offer greater rubber resistance if additives such as silica or beads are applied in conjunction with the paint. The use of additives such as silica and/or beads offers friction benefits as compared with unbeaded paint without silica.

Based on the results of this evaluation effort, it is concluded that:

- Retro-reflectivity readings of the beaded materials varied between products over the one-year evaluation. Initial readings confirmed the higher reflectivity of the 1.9 IOR glass beads during the early period following application. Over time, a reduction occurred in retro-reflectivity of the 1.9 beaded materials while the 1.5 beaded materials tended to sustain a level performance. At the completion of the one-year test period, all 1.5 beaded materials at the Atlantic City and Pittsburgh test sites had higher retro-reflectivity than their 1.9 counterparts.

- The performance of beaded paint appears to offer positive friction benefits as compared with non-beaded paint. The use of silica and beads as dropped-on additives provides positive friction benefits on runways and serves to resist rubberization.

- A comparison was made between 1.5 and 1.9 IOR beads as viewed from the cockpit of various type aircraft in both an airborne and taxi configuration. Three airborne evaluations of the beaded threshold and centerline markings at the Atlantic City airport confirmed that the amount of light reflected back to the pilot from the left threshold stripe (1.9 IOR) was slightly higher than that of the right threshold stripe (1.5 IOR) only when the aircraft's landing lights were in close proximity to the pilots eye. A difference between the two threshold stripes was not evident from the cockpit of the Convair 580 which has wing root landing lights. It is considered significant that the non-beaded stripes were not visible to the pilots. No significant differences were noted concerning the effectiveness of the beaded centerline markings during the back taxi portion of the evaluation. The threshold marking with the 1.9 bead was visually acquired prior to the 1.5 beaded stripe during the back taxiing only with the Piper Arrow and the Aero Commander with the landing lights on the nose gear and not the Convair 580.

- Data from the reflectivity readings showed that the durability of 1.5 IOR glass beads is greater than 1.9 IOR glass beads in an airport environment. Some of the degredation of the 1.9 bead can be attributed to snow plow strikes. The 1.9 bead has a larger diameter than the 1.5 IOR bead allowing more of the bead to be exposed and increase the probability of being dislodged by snow plows. The 1.5 IOR beads did not show the same effects from the snow plows. An advantage of the 1.5 IOR beads is that they are made up of a large number of smaller spheres. Some of these sheres submerge into the paint and only become exposed over time thus being able to sustain their reflectivity at high levels. The smaller spheres also allow more beads to be in place per square inch of the marking and they have approximately half the weight by volume of the 1.9 beads giving you approximately twice the number of reflective beads per pound.

- The use of retro-reflective glass beads in airport pavement markings, whether they be Type I (1.5 IOR) or Type III (1.9 IOR), greatly enhance the conspicuity of the markings on all airport surfaces. This enhancement is amplified on airports without runway centerline or touchdown zone lighting. Throughout this research effort there were no findings that would require limiting the use of glass beads to certain airport surfaces.

- The 1.5 IOR beads give an airport that may not have the funding to use the more expensive 1.9 IOR bead in the pavement markings an affordable alternative to enhance the conspicuity of the pavement markings thus increasing the safety of surface operations.

6. REFERENCES.

1. TT-B-1325B, "Beads (Glass Spheres) Retro-Reflective", Federal Specification

2. Advisory Circular 150/5340-1G, Marking of Paved Areas on Airports, Washington, DC 20591.

3. AC 150/5370-10A, Standards for Specifying Construction on Airports, Washington, DC 20591.

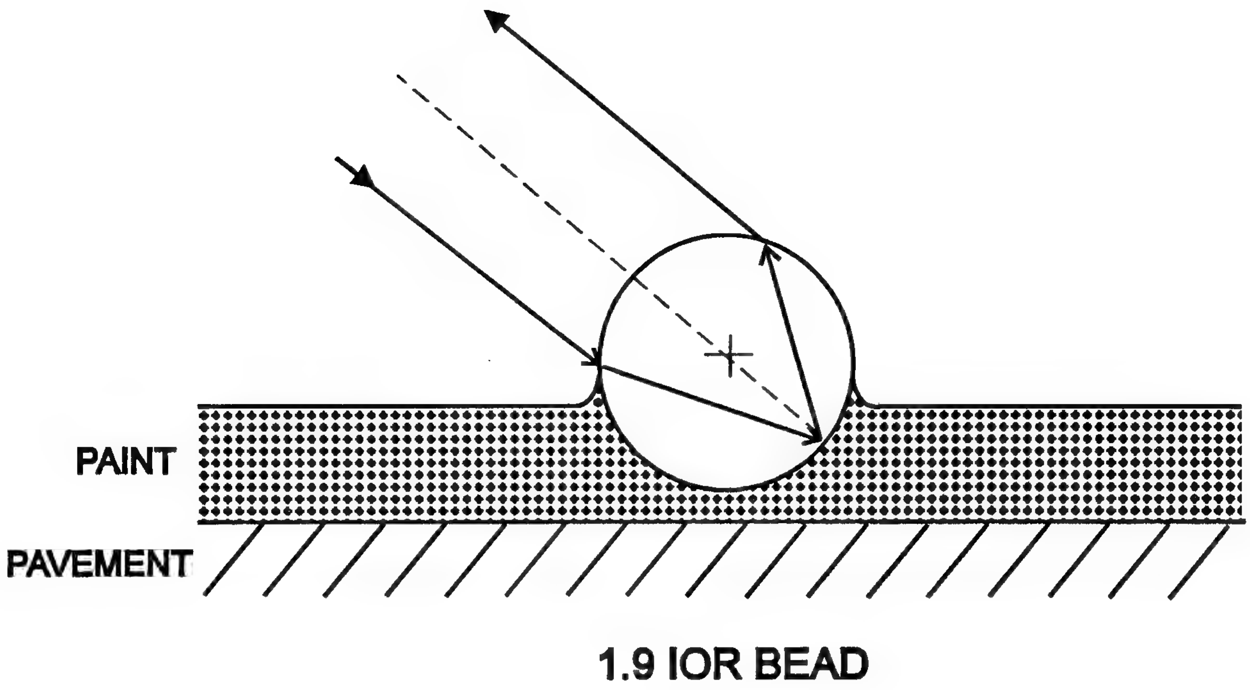
4. Letter to Technical Program Manager, ACD-110, dated 11 March 1993, from Commander Headquarters Air Force Civil Engineering Agency, Tyndall AFB, FL 32403.

5. Letter to Air Force Commands, 6 August 1992, from D.S. O'Brien,Headquarters Air Force Civil Engineering Agency, Tyndall AFB, FL 32403.

6. AC 150/5320-12B, Measurement, Construction, and Maintenance of Skid-Resistant Airport Pavement Surfaces, Washington DC 20591.

7. Letter to Technical Program Manager, ACD-110, dated 27 October 1993, from Mr. Raymond Hoffelt, Airfield Operations Supervisor, O'Hare Airport, Chicago, IL 60602.

APPENDIX A - RUNWAY / TAXIWAY TEST CONFIGURATIONS, RETRO-REFLECTIVITY MEASUREMENTS, AND INSPECTION PHOTOGRAPHS



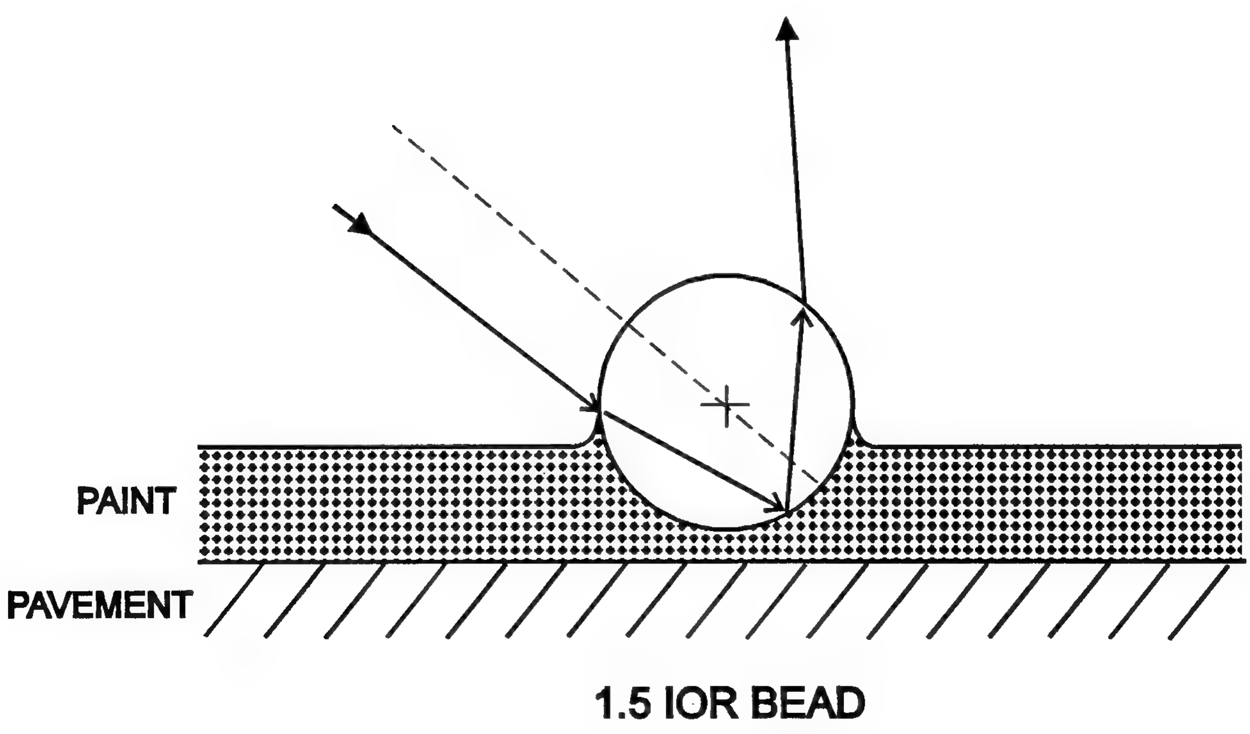


FIGURE A-1. INDEX OF REFRACTION COMPARISON

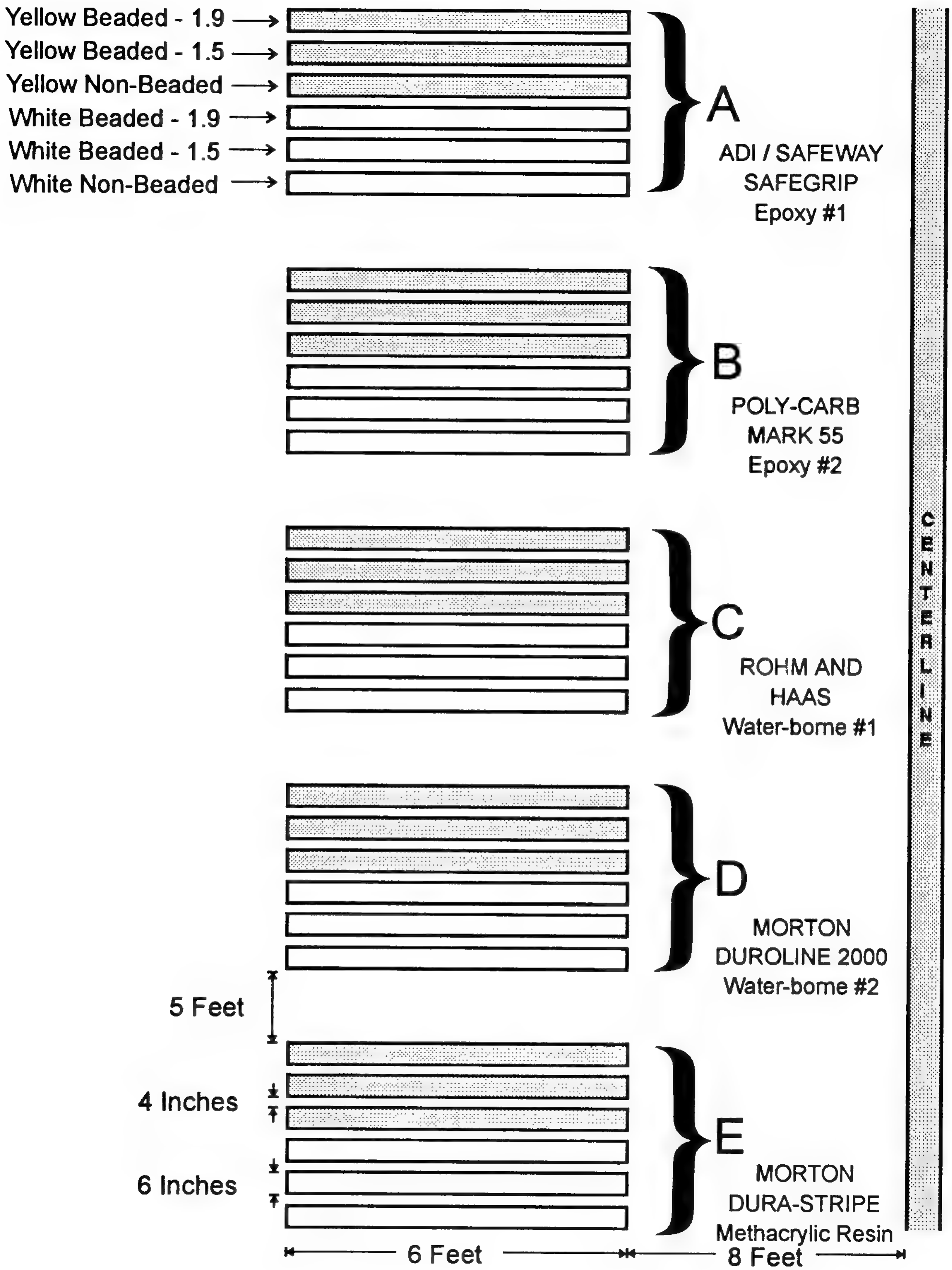


FIGURE A-2. TAXIWAY MARKING TEST LAYOUT

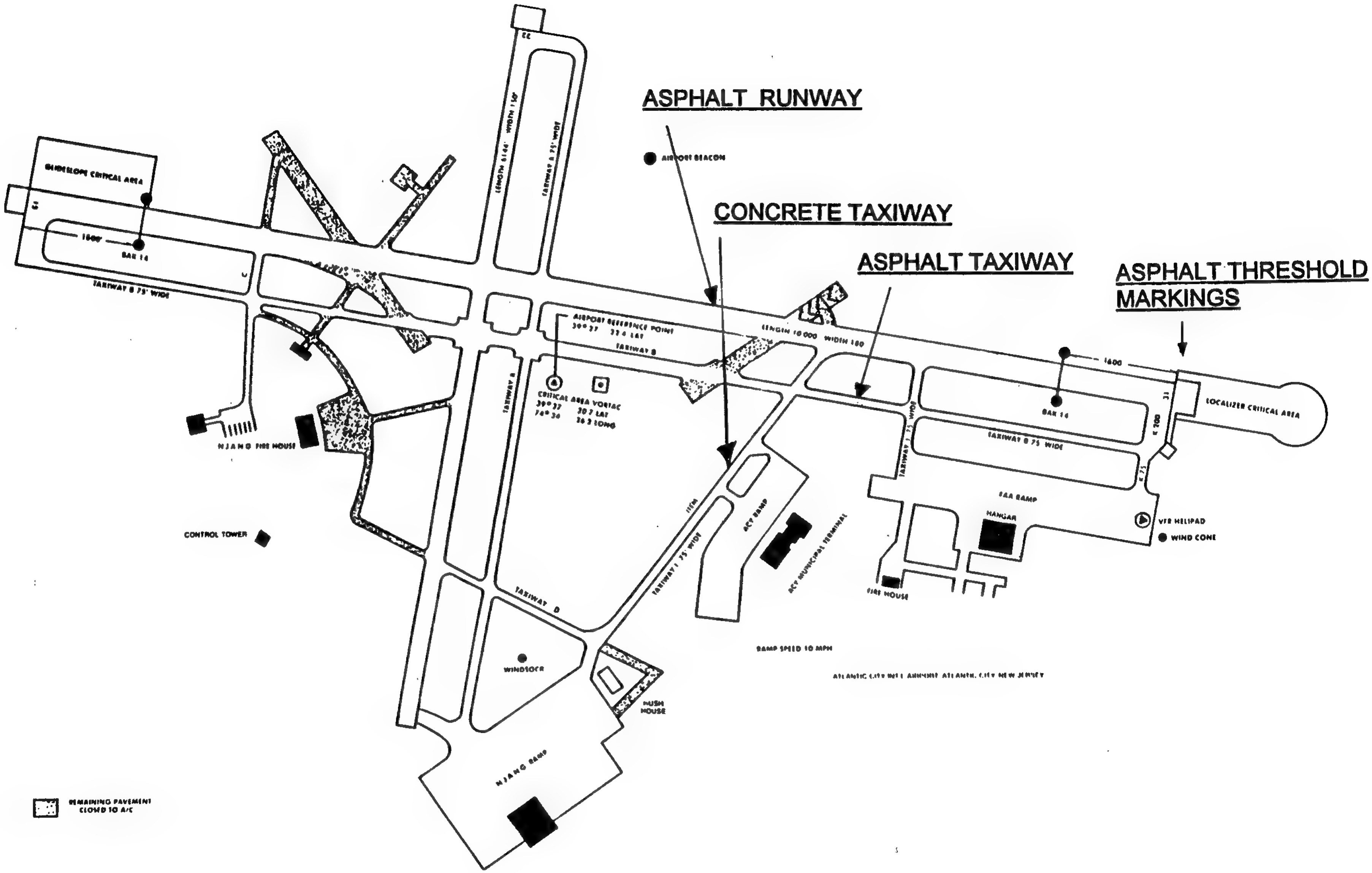


FIGURE A-3. ATLANTIC CITY INTERNATIONAL AIRPORT DIAGRAM

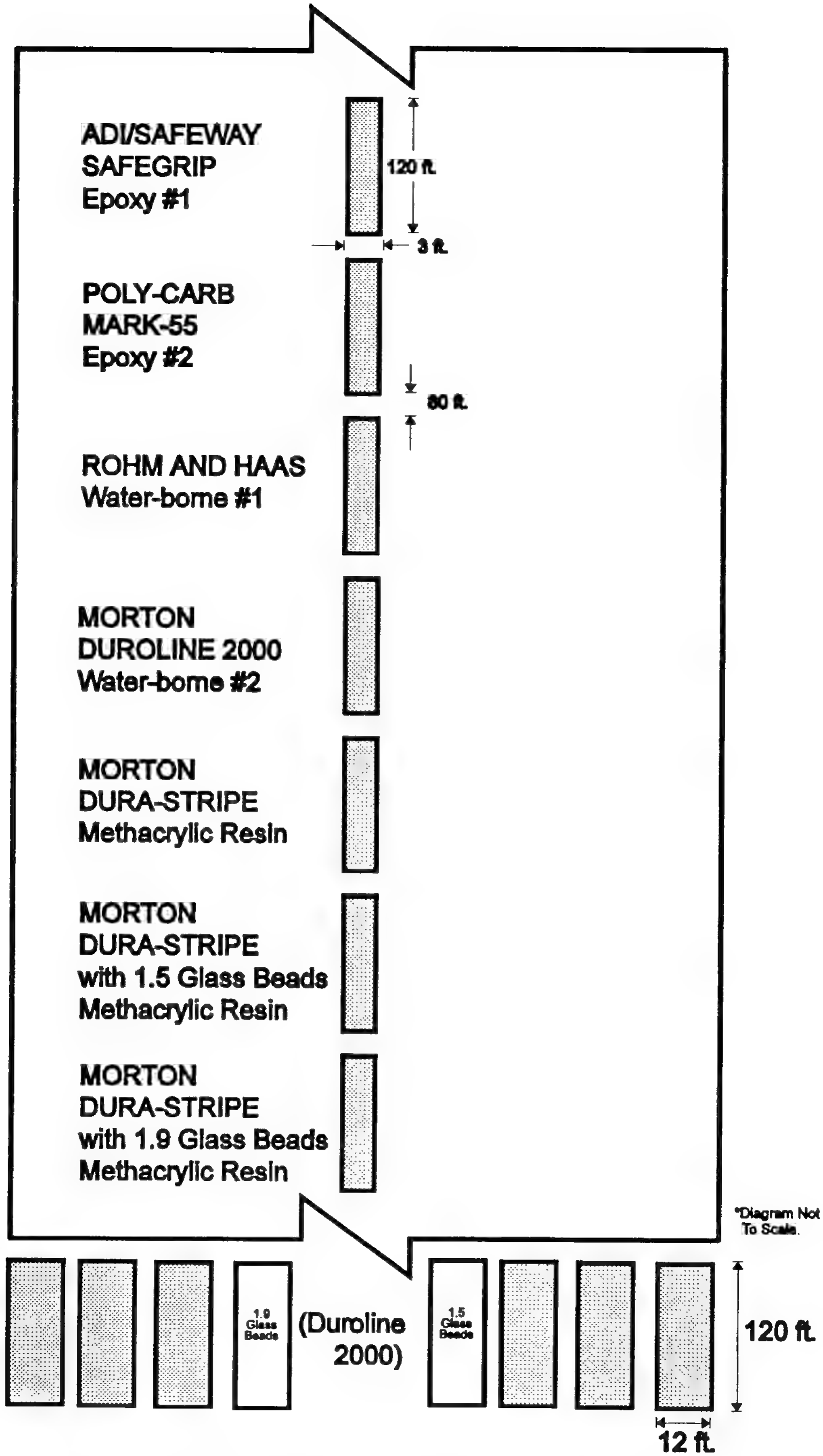


FIGURE A-4. ATLANTIC CITY RUNWAY TEST MARKINGS

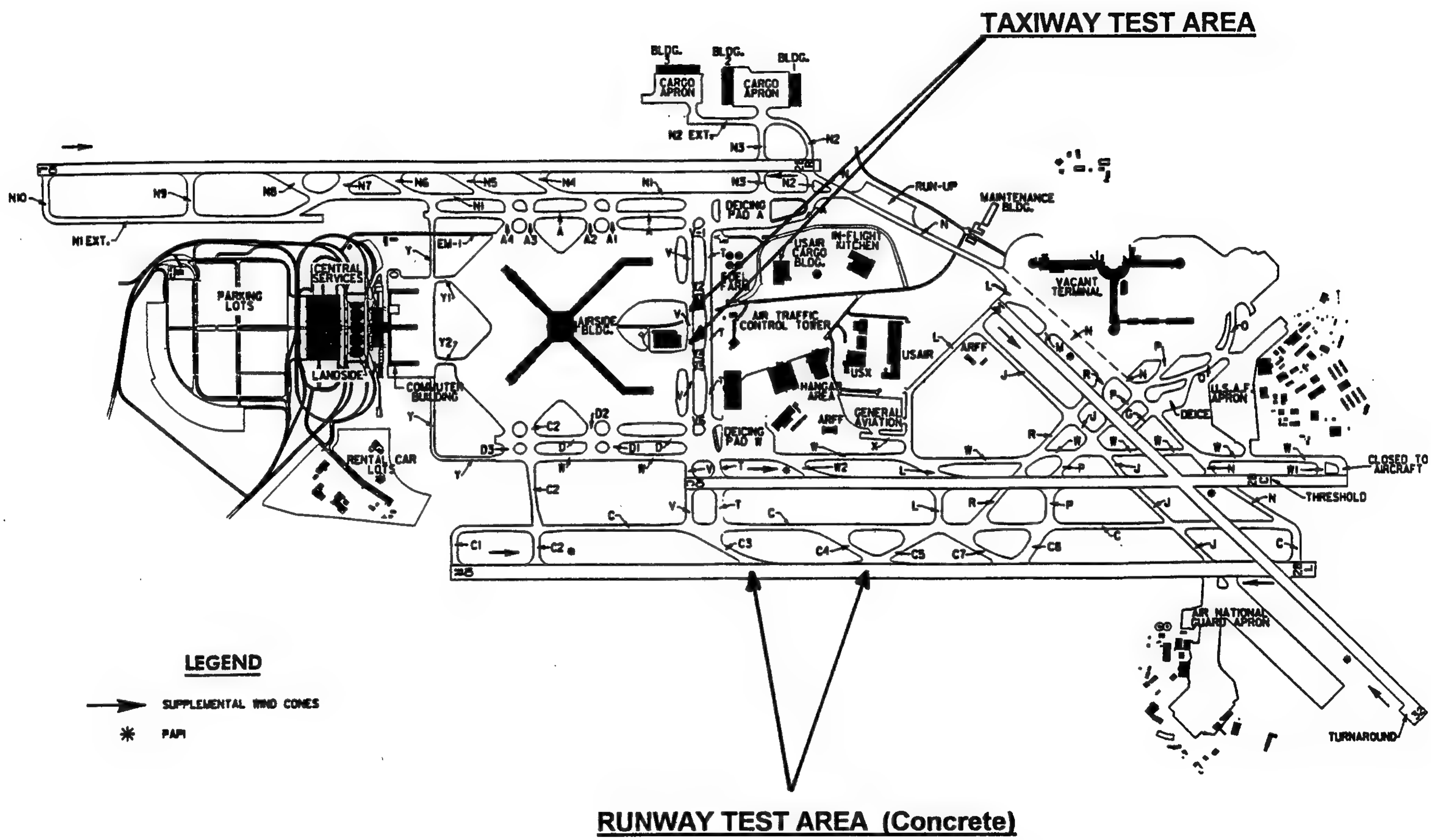


FIGURE A-5. GREATER PITTSBURGH INTERNATIONAL AIRPORT DIAGRAM

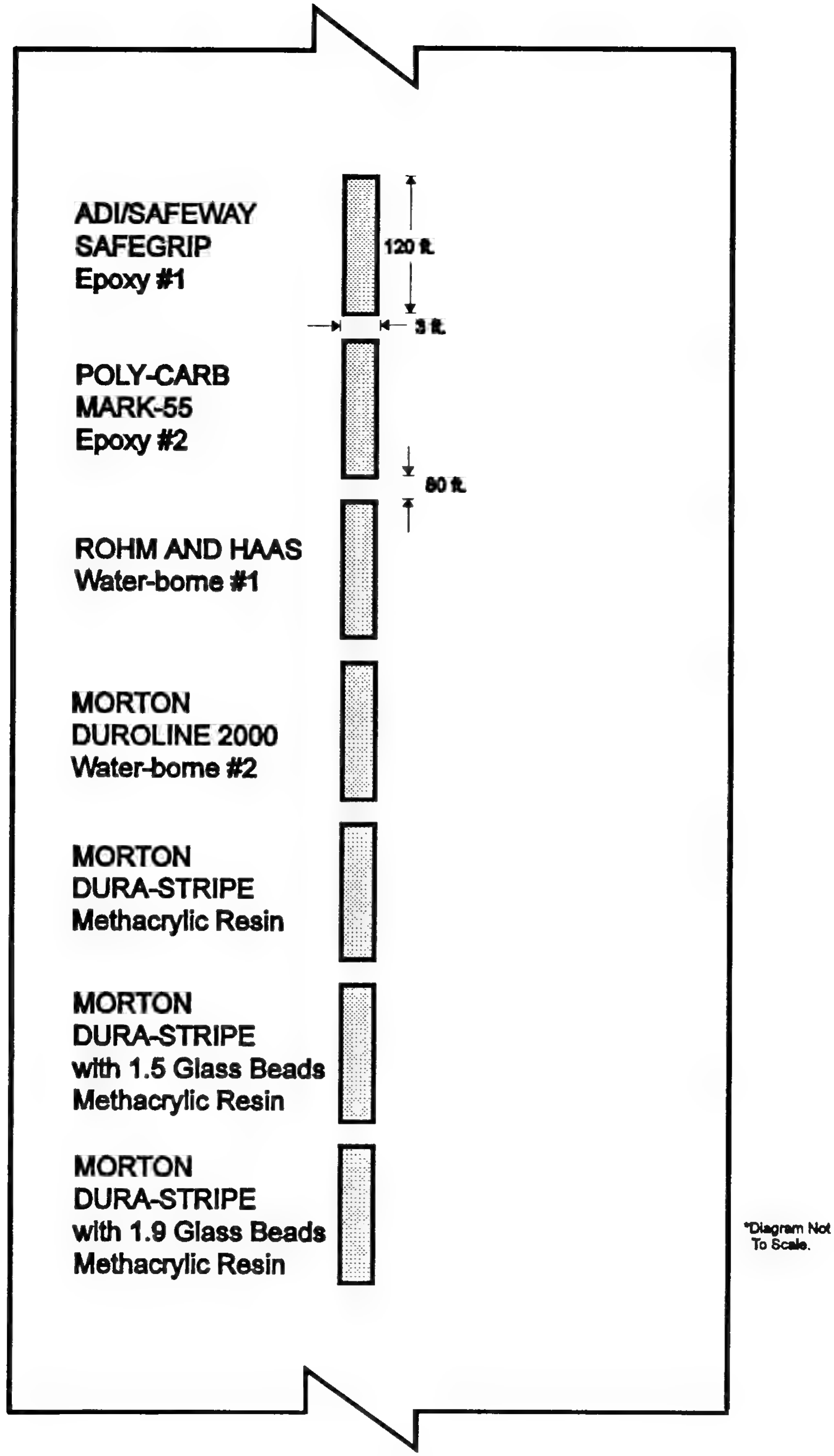


FIGURE A-6. PITTSBURGH RUNWAY TEST MARKINGS

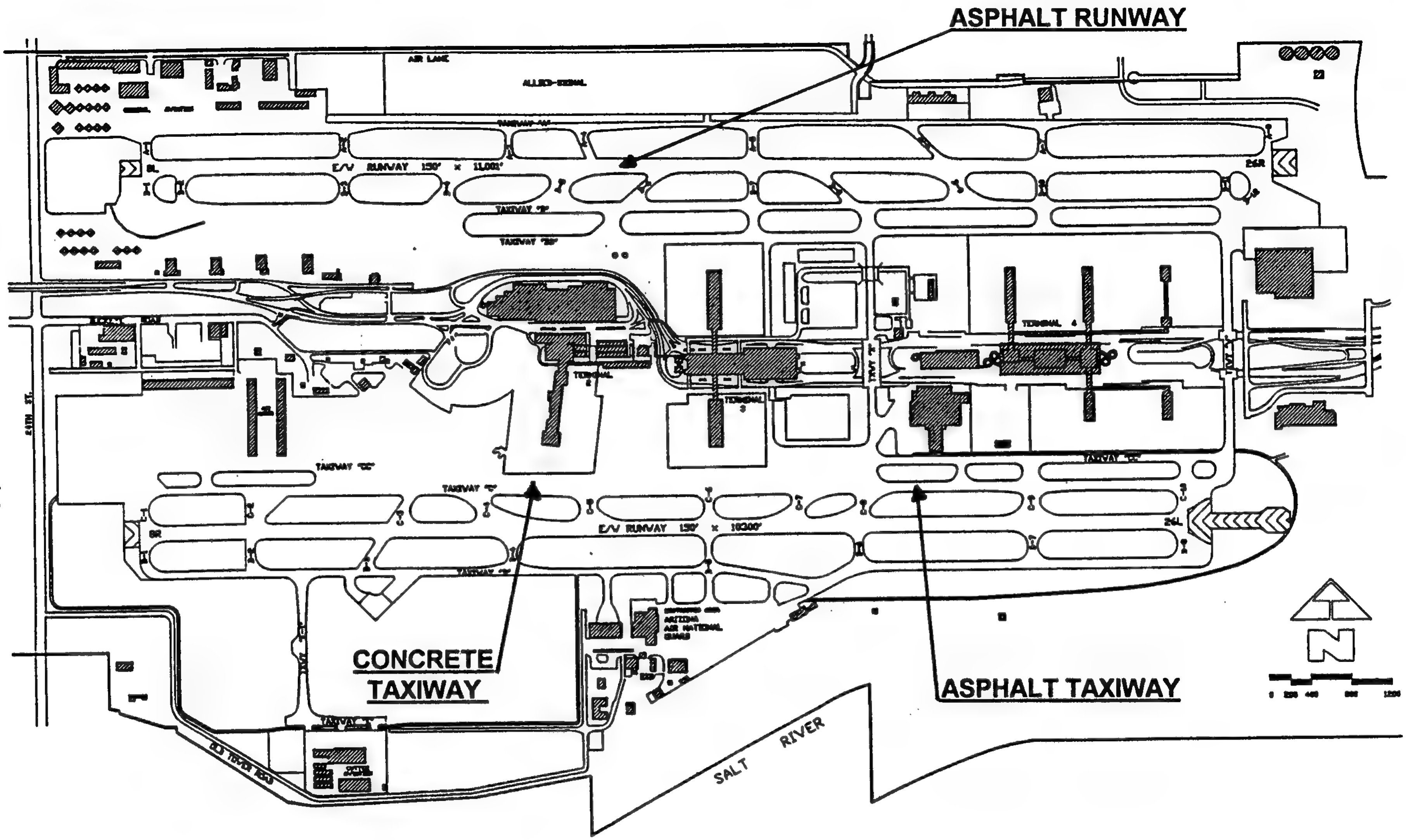


FIGURE A-7. PHOENIX SKY HARBOR INTERNATIONAL AIRPORT DIAGRAM

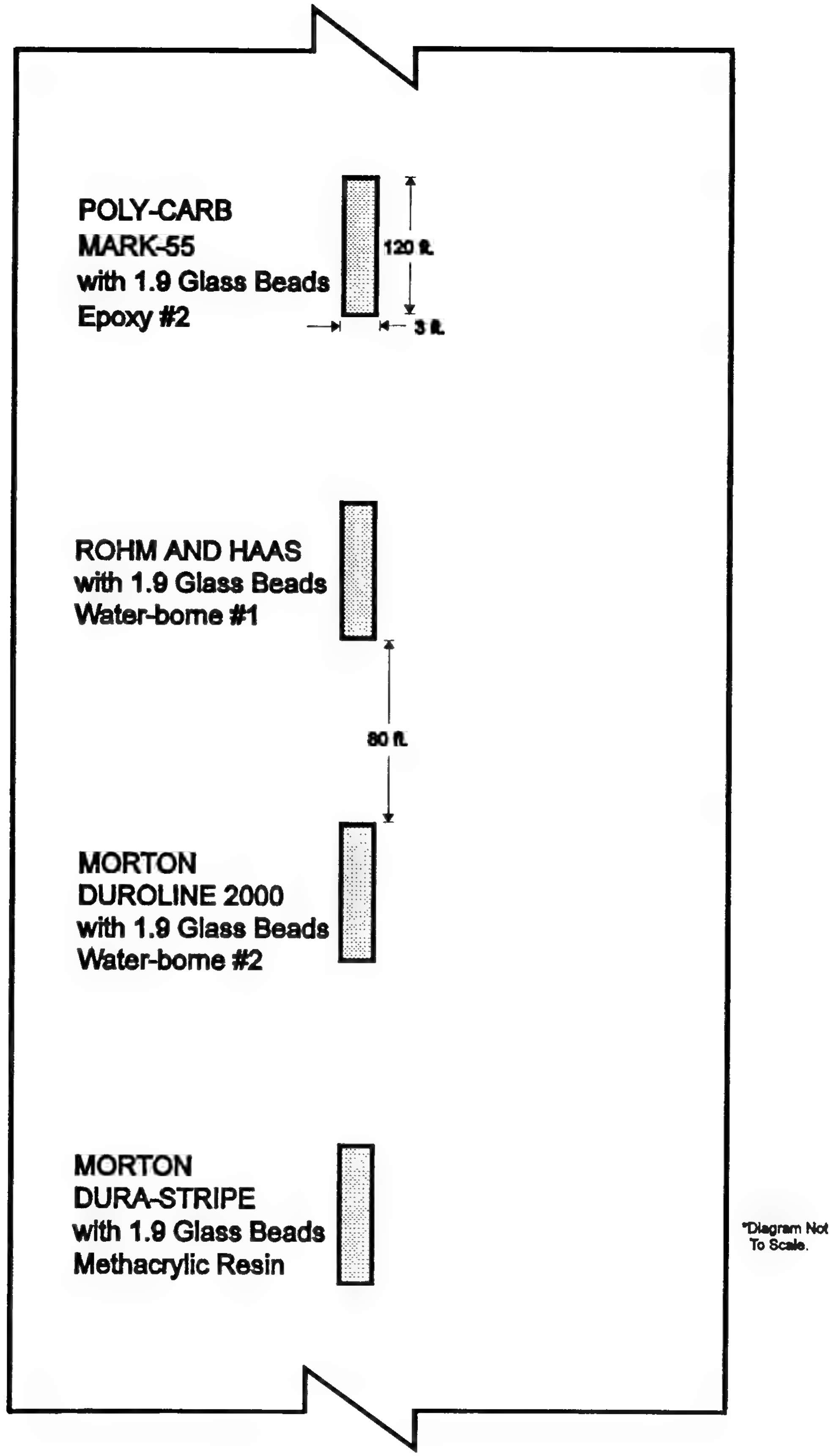


FIGURE A-8. PHOENIX RUNWAY TEST MARKINGS

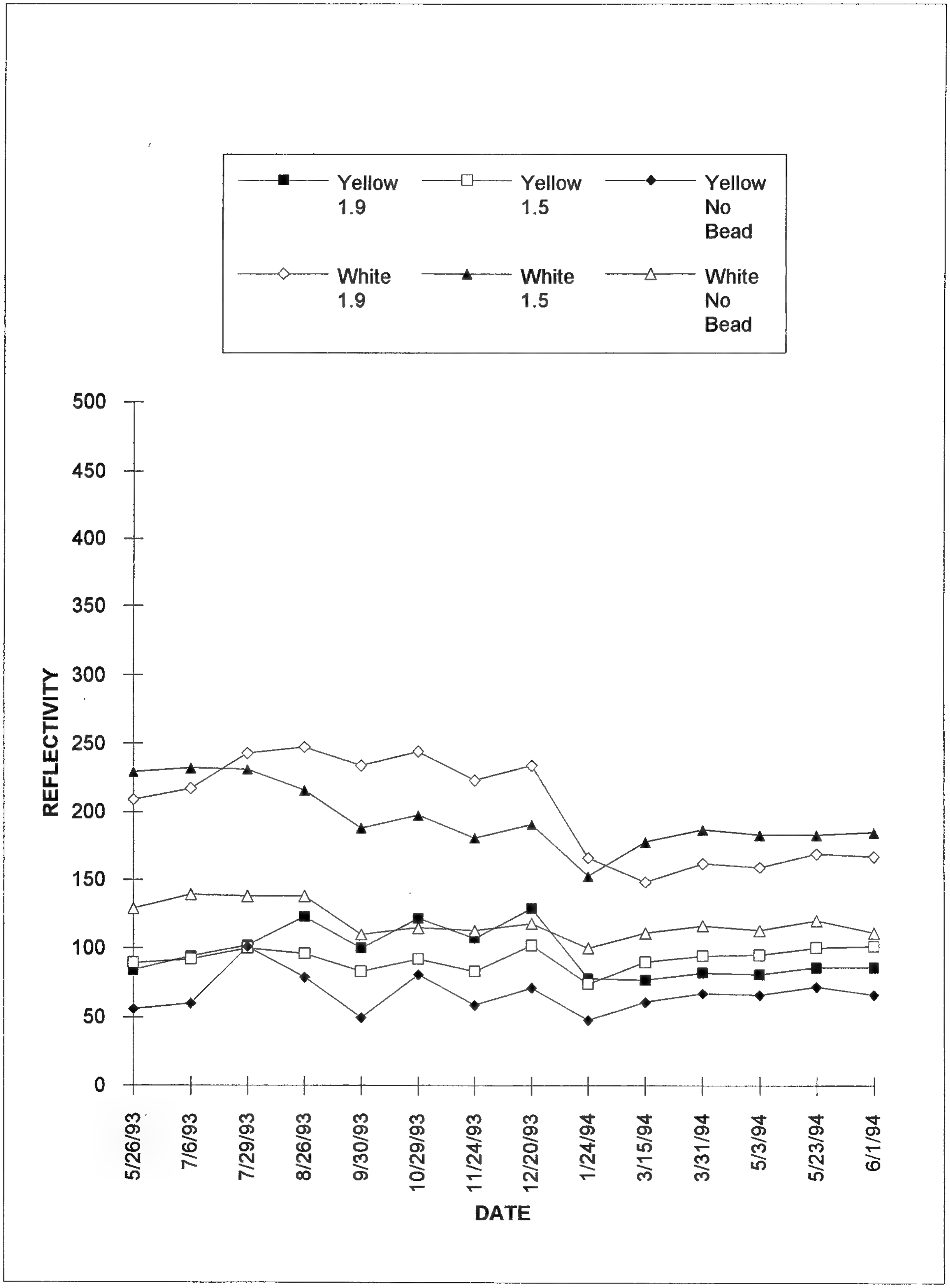


FIGURE A-9. ATLANTIC CITY - ADI/SAFEWAY - CONCRETE

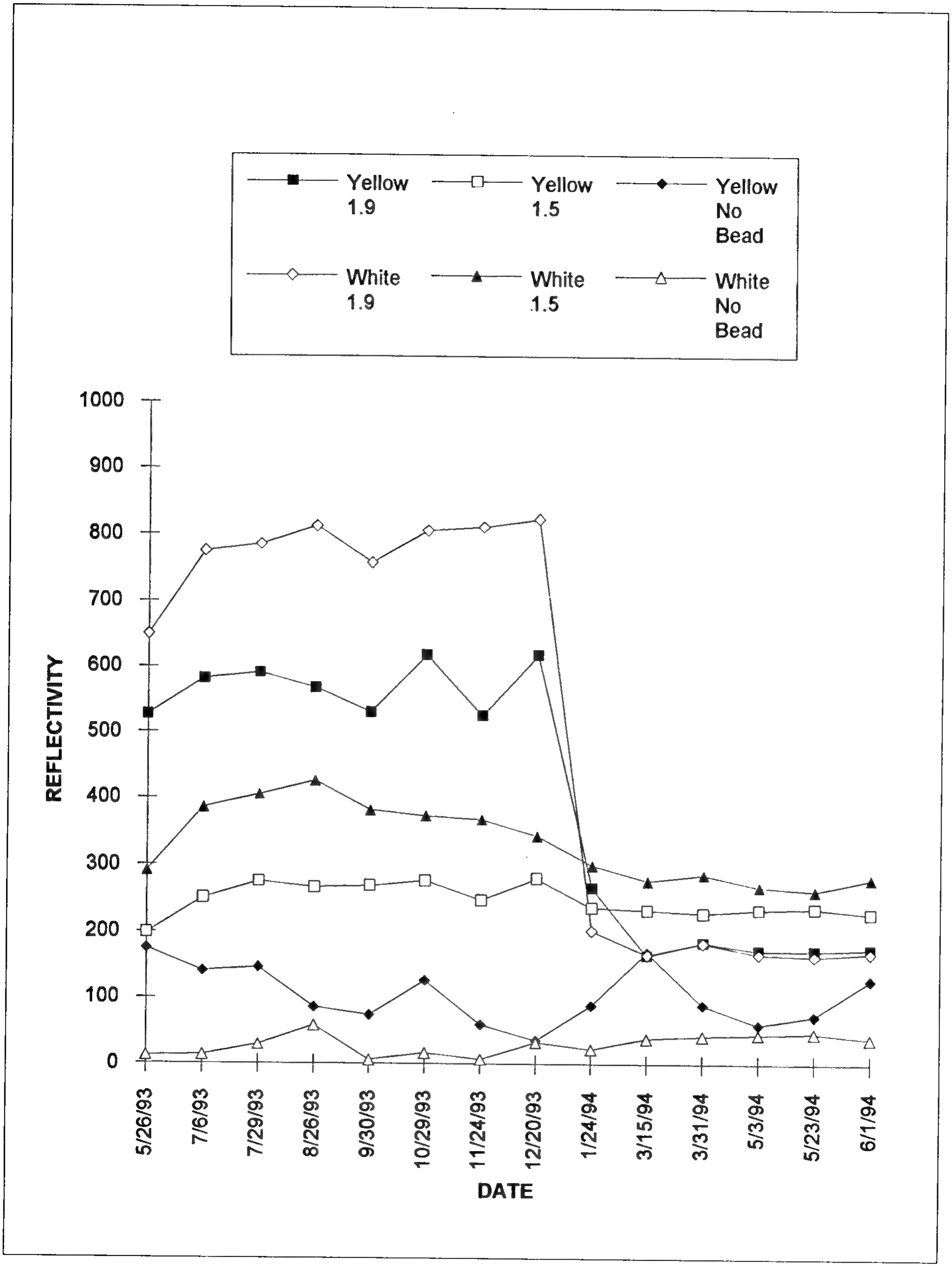


FIGURE A-10. ATLANTIC CITY - POLY-CARB - CONCRETE

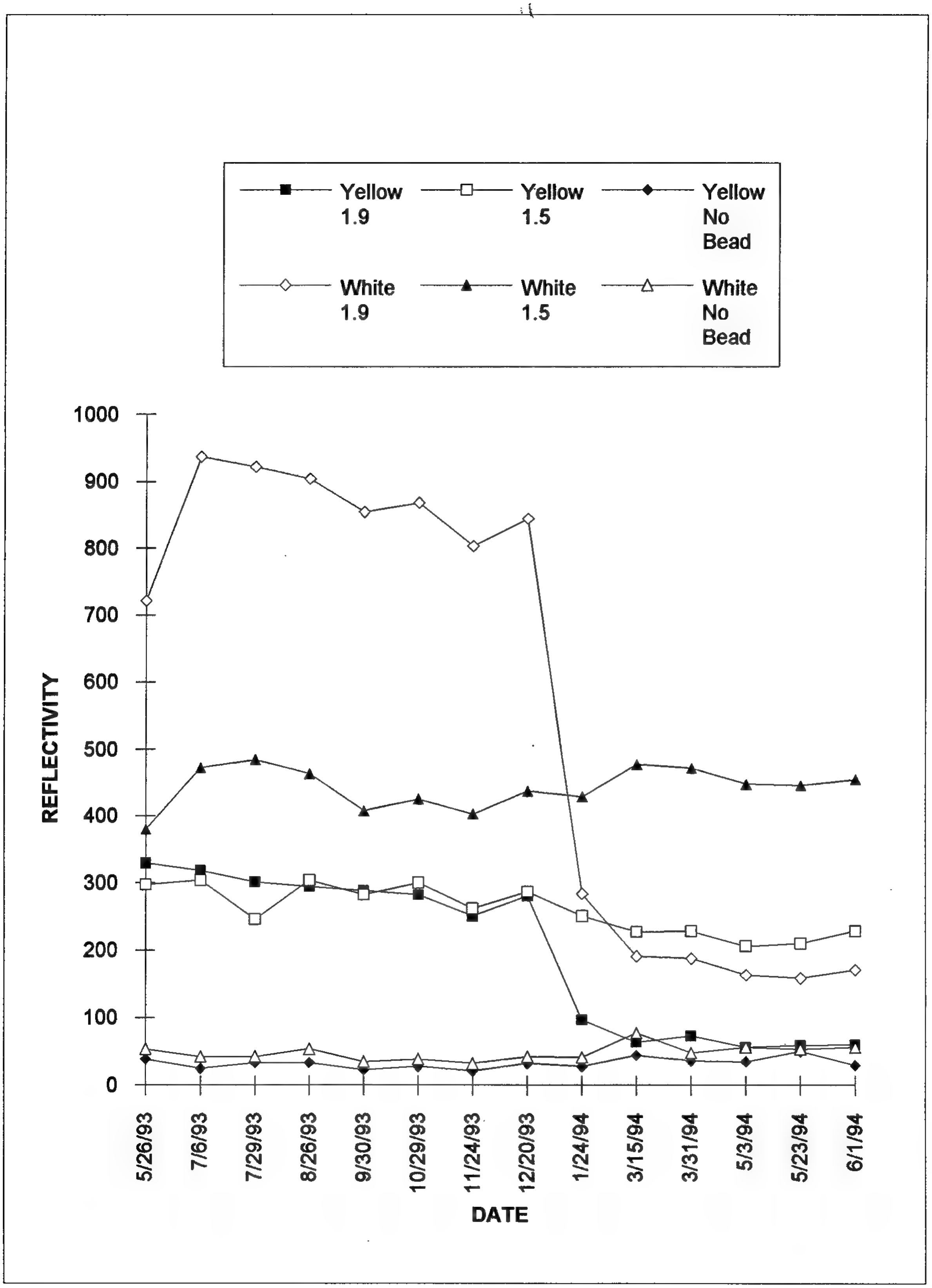


FIGURE A-11. ATLANTIC CITY - ROHM AND HAAS - CONCRETE

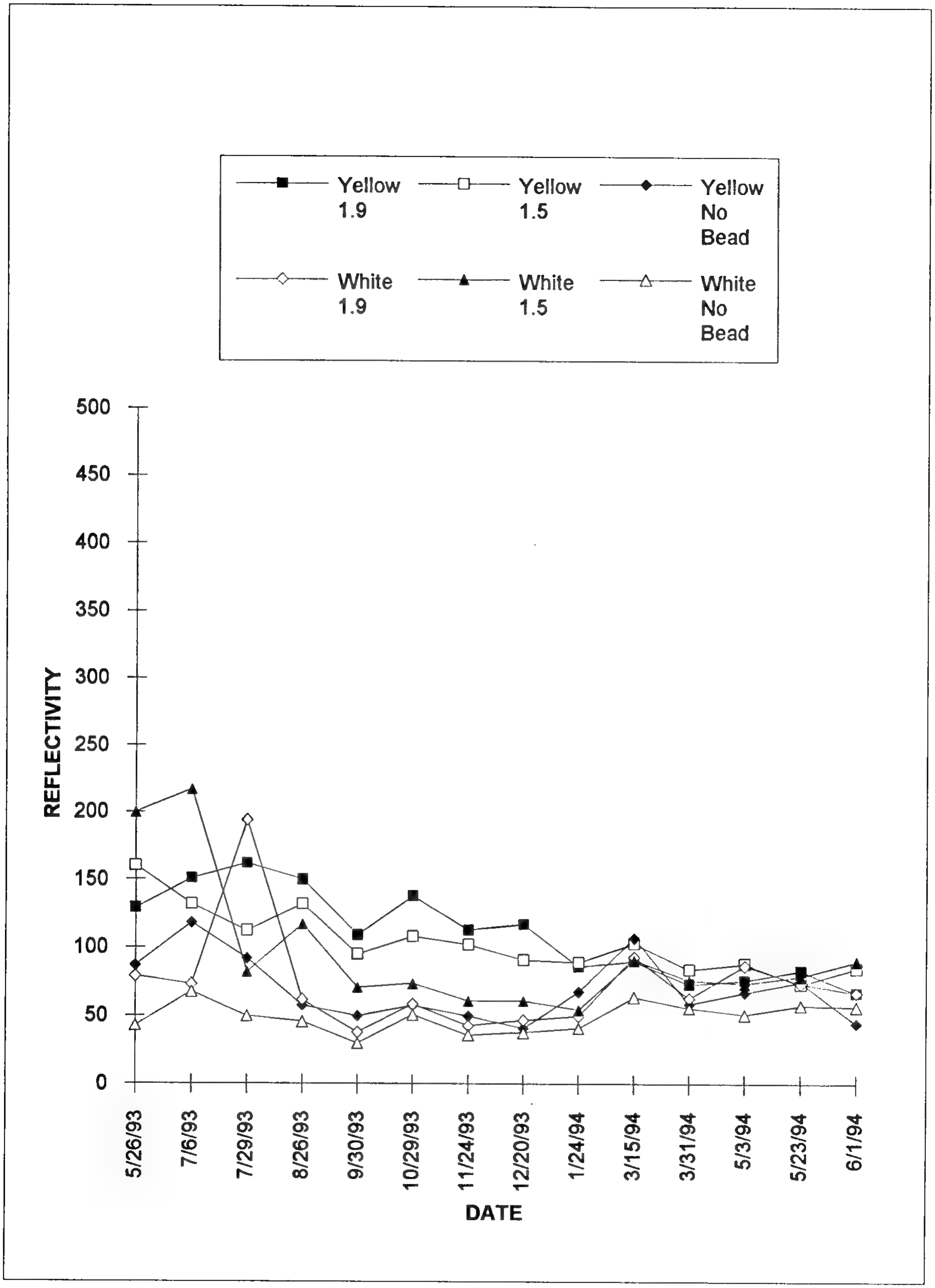


FIGURE A-12. ATLANTIC CITY - MORTON DUROLINE - CONCRETE

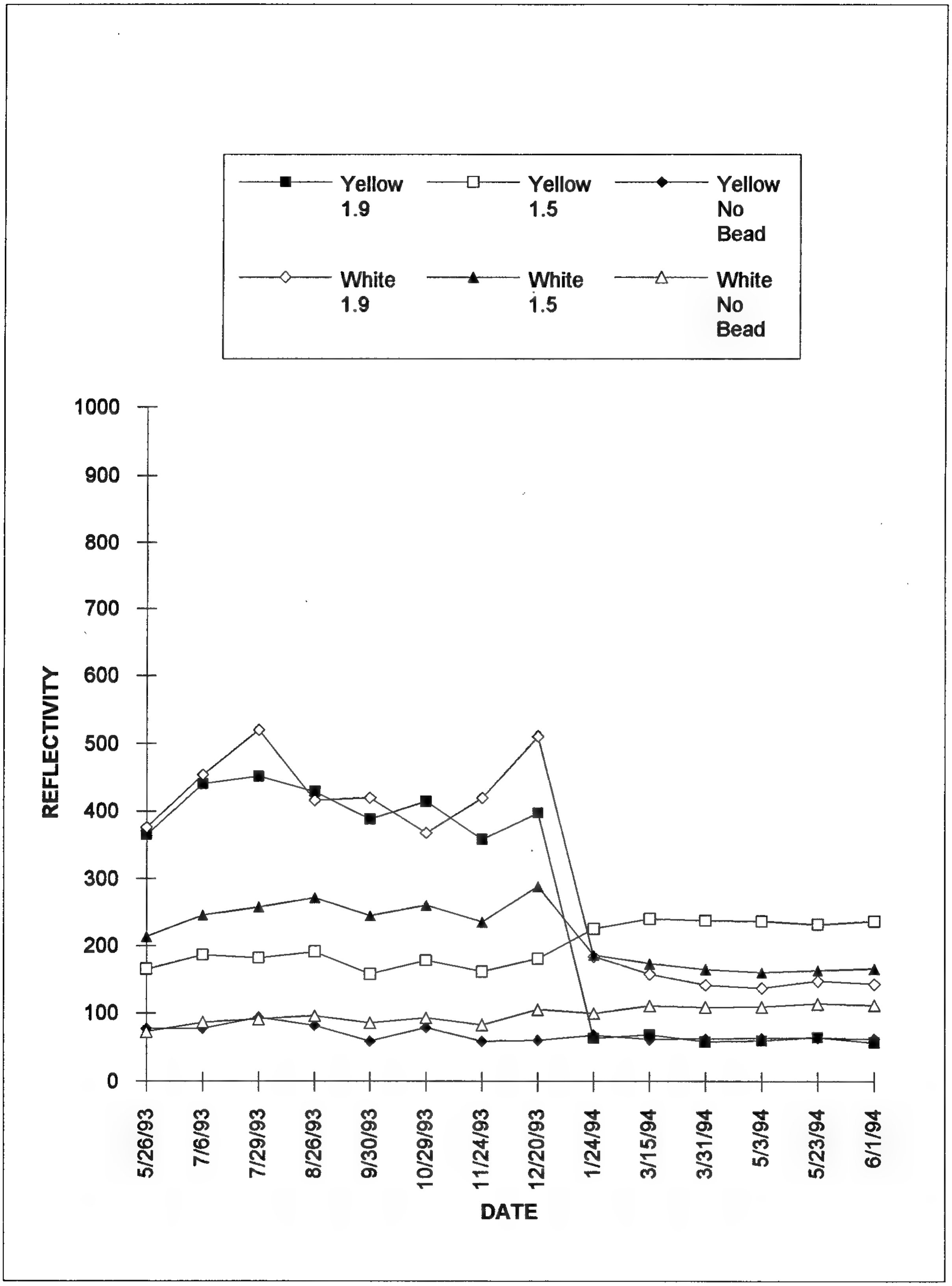


FIGURE A-13. ATLANTIC CITY - MORTON DURA-STRIPE - CONCRETE

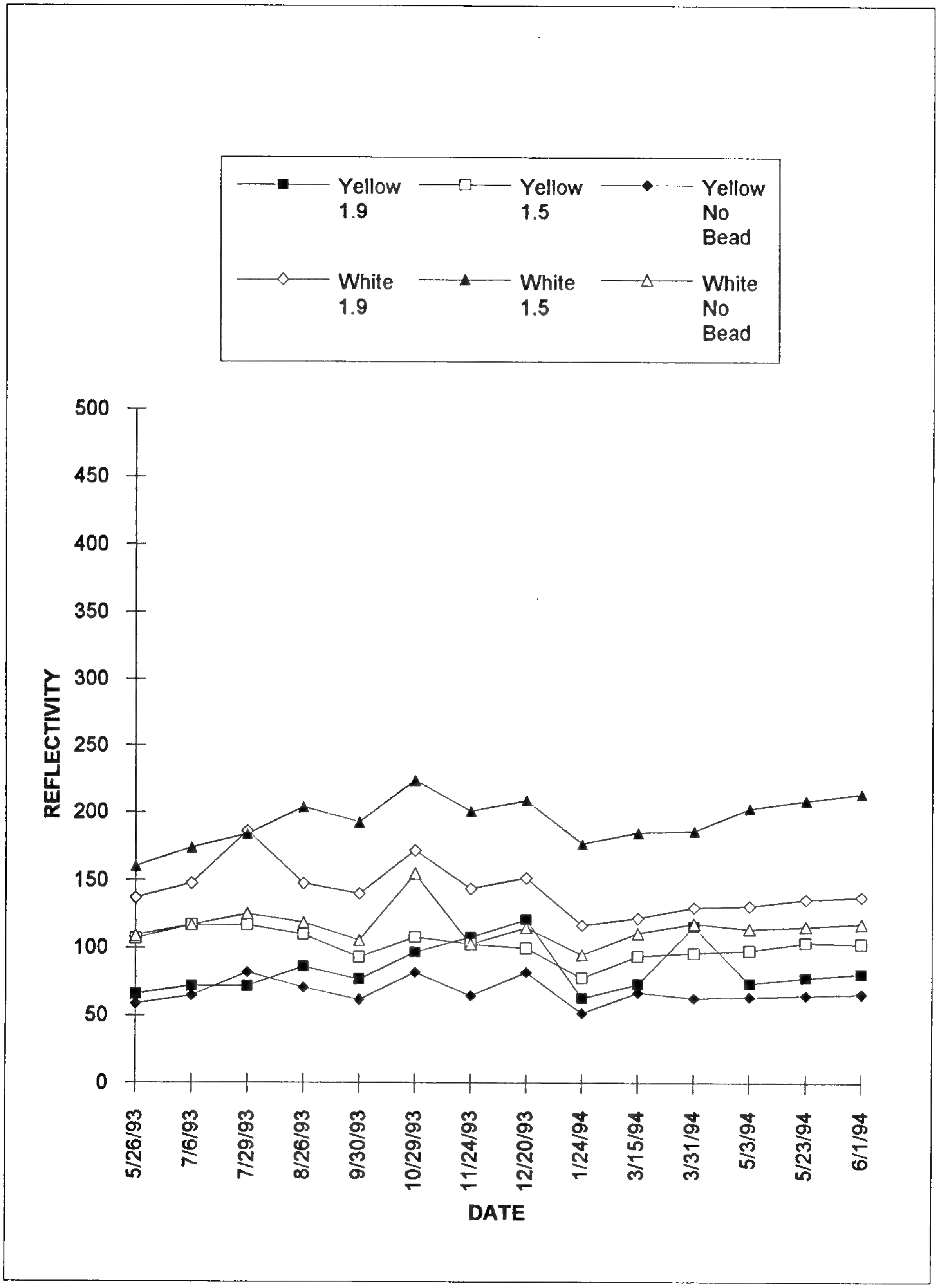


FIGURE A-14. ATLANTIC CITY - ADI/SAFEWAY - ASPHALT

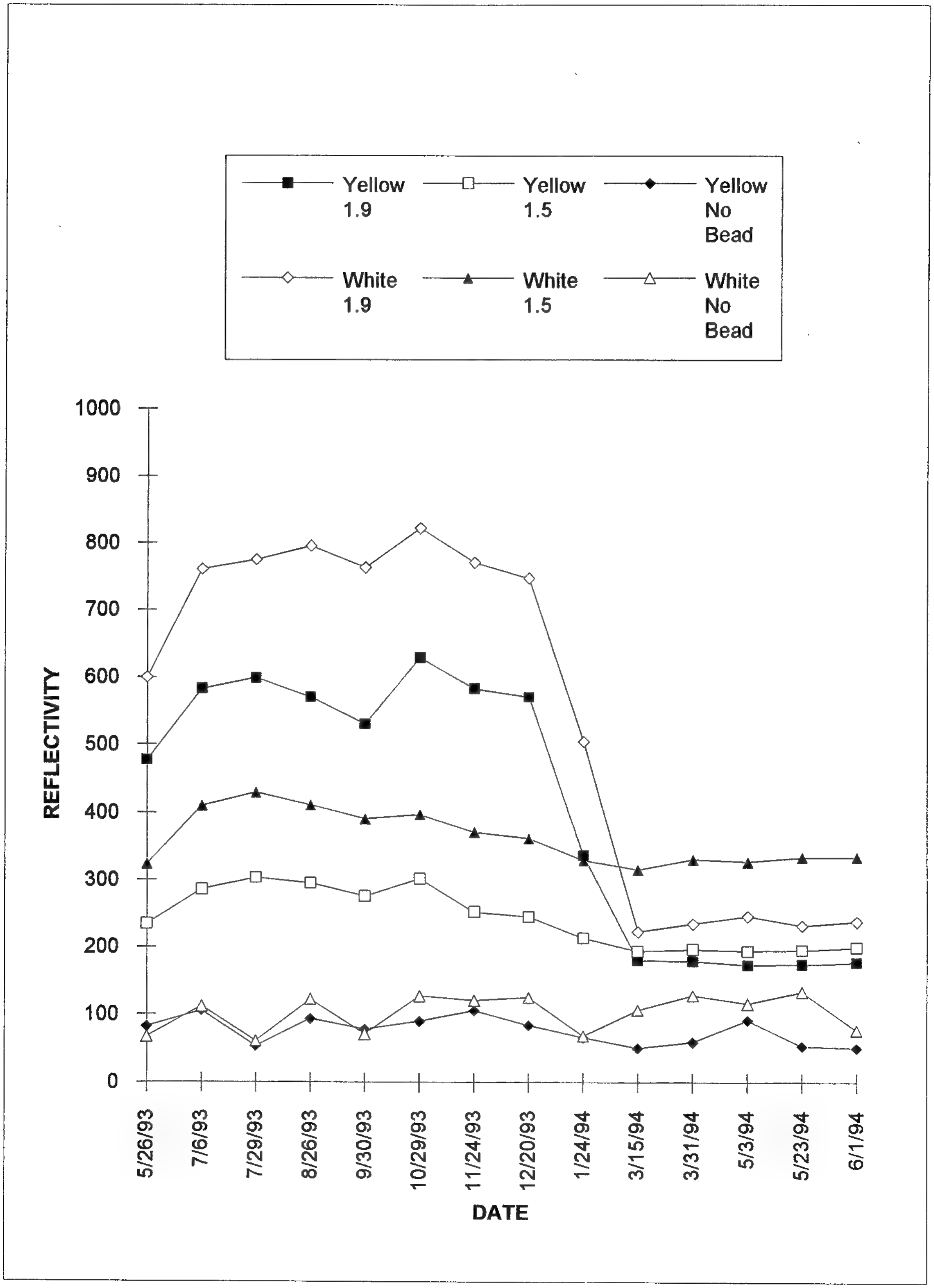


FIGURE A-15. ATLANTIC CITY - POLY-CARB - ASPHALT

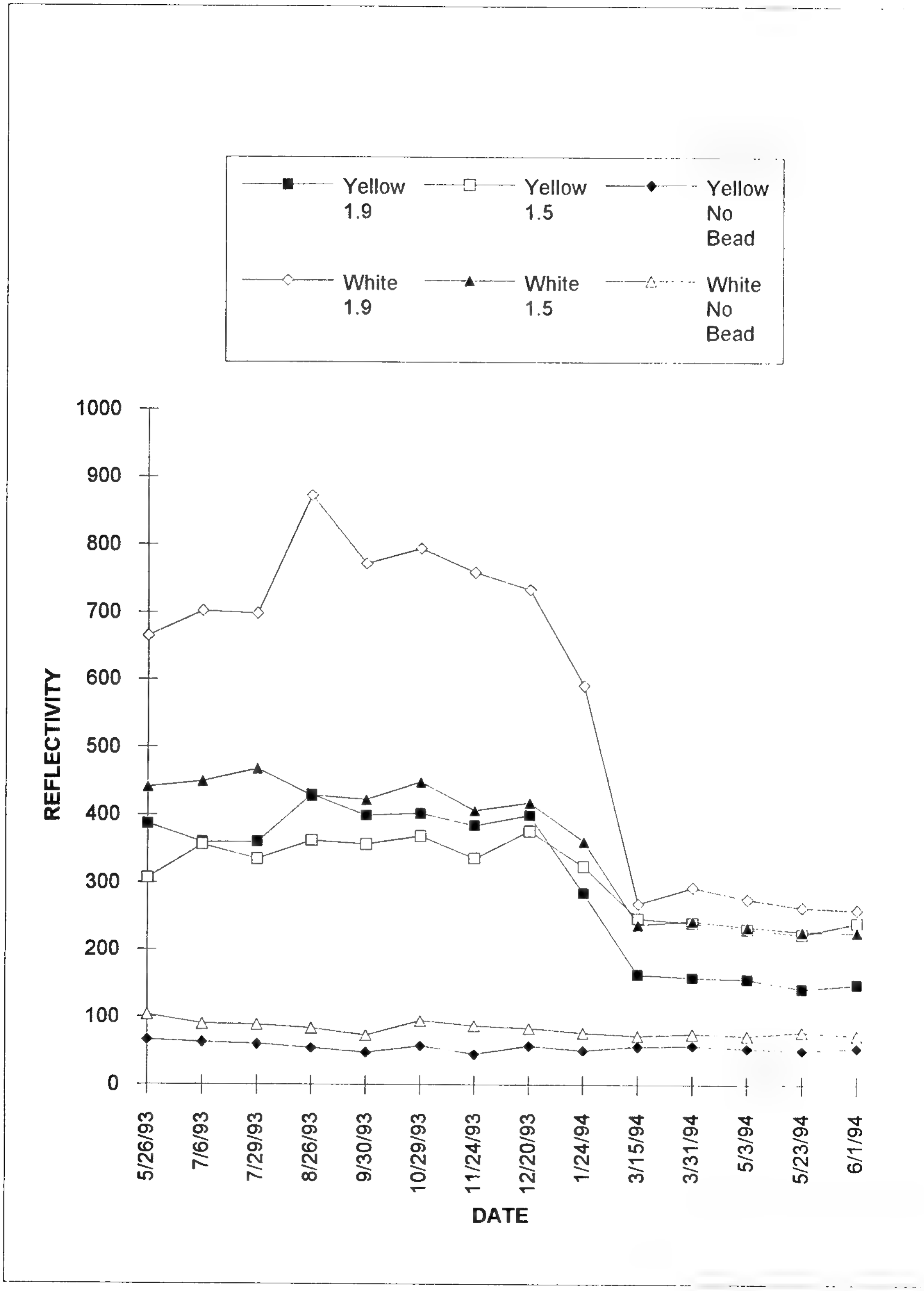


FIGURE A-16. ATLANTIC CITY - ROHM AND HAAS - ASPHALT

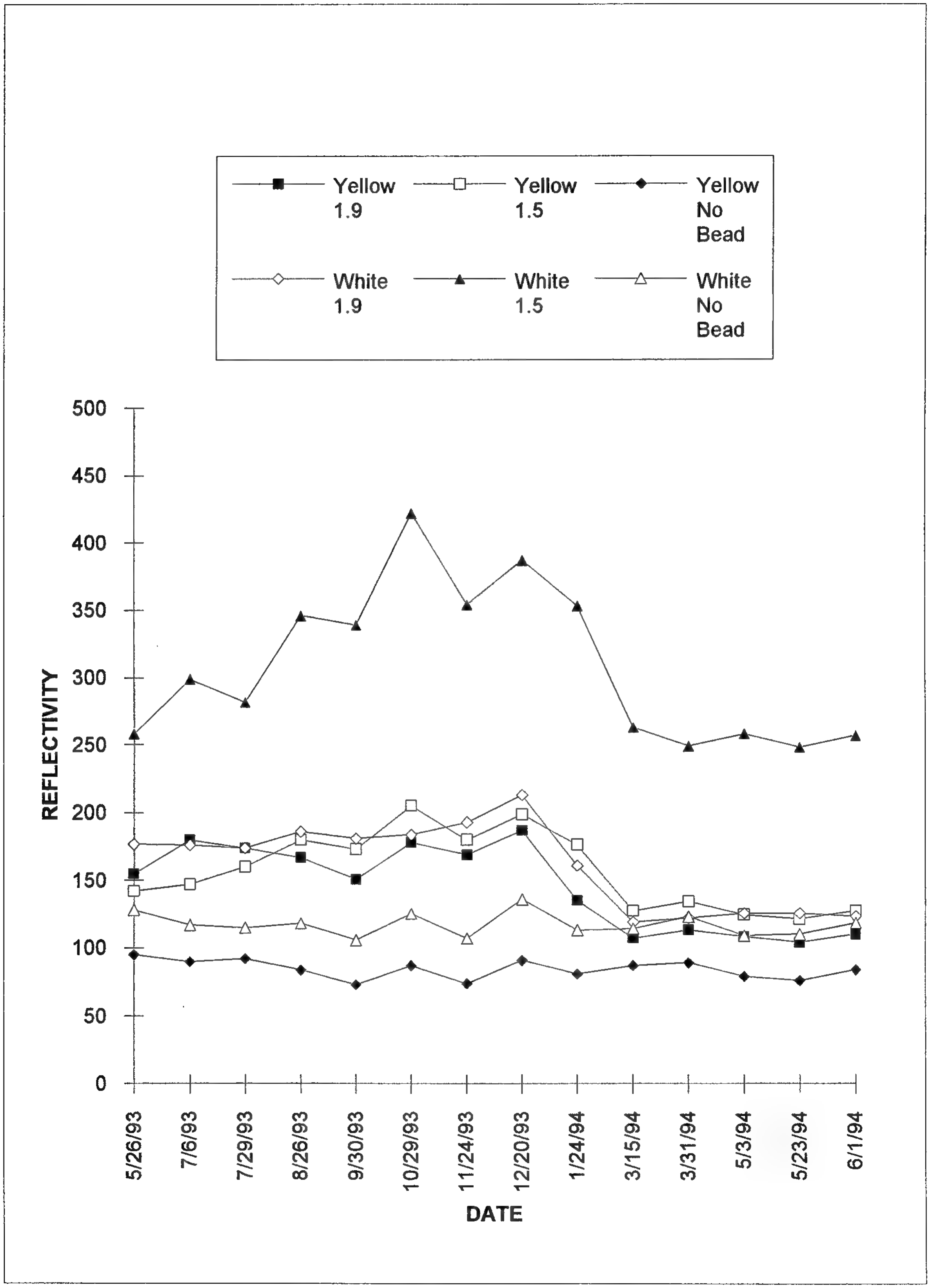


FIGURE A-17. ATLANTIC CITY - MORTON DUROLINE - ASPHALT

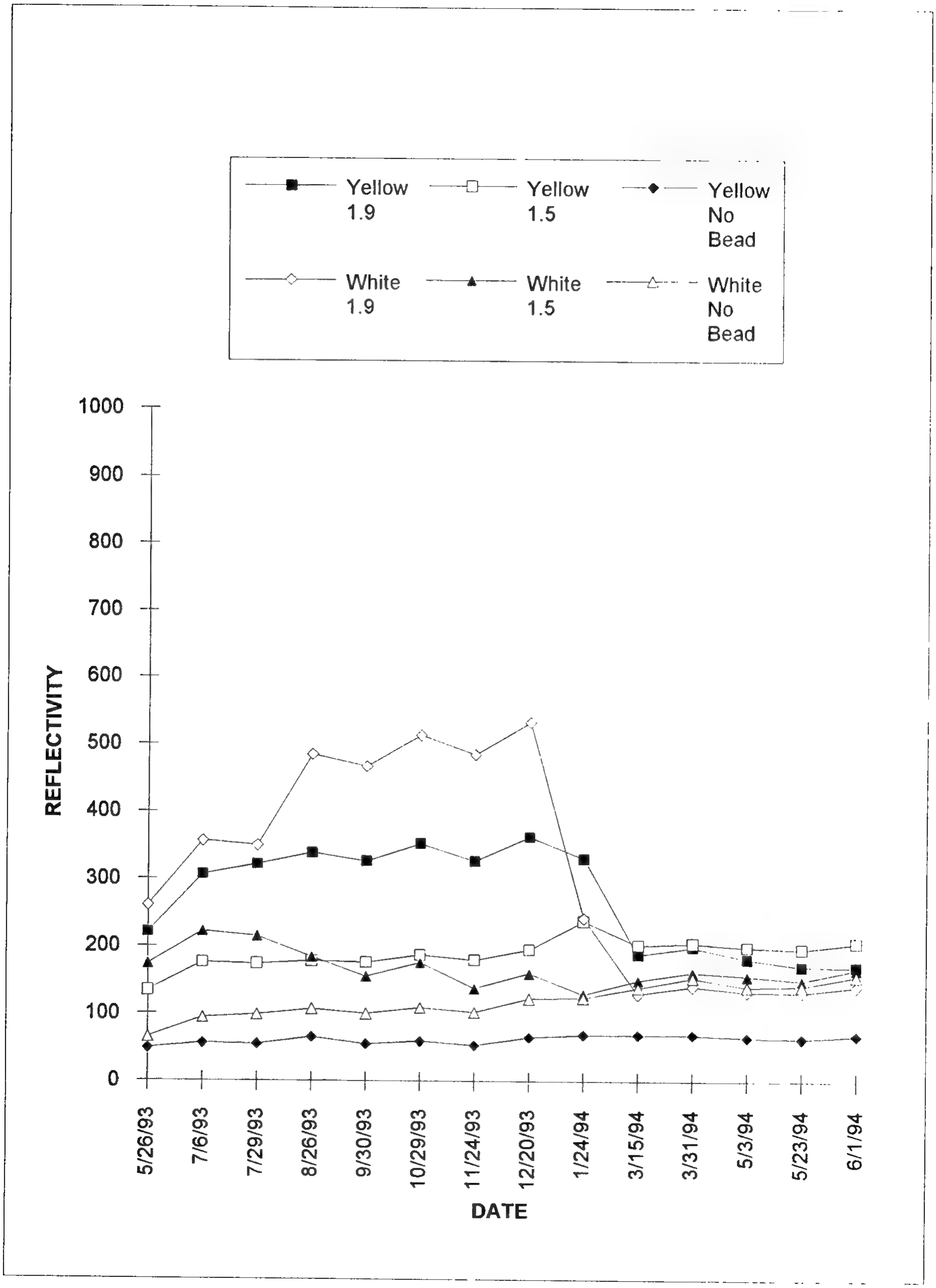
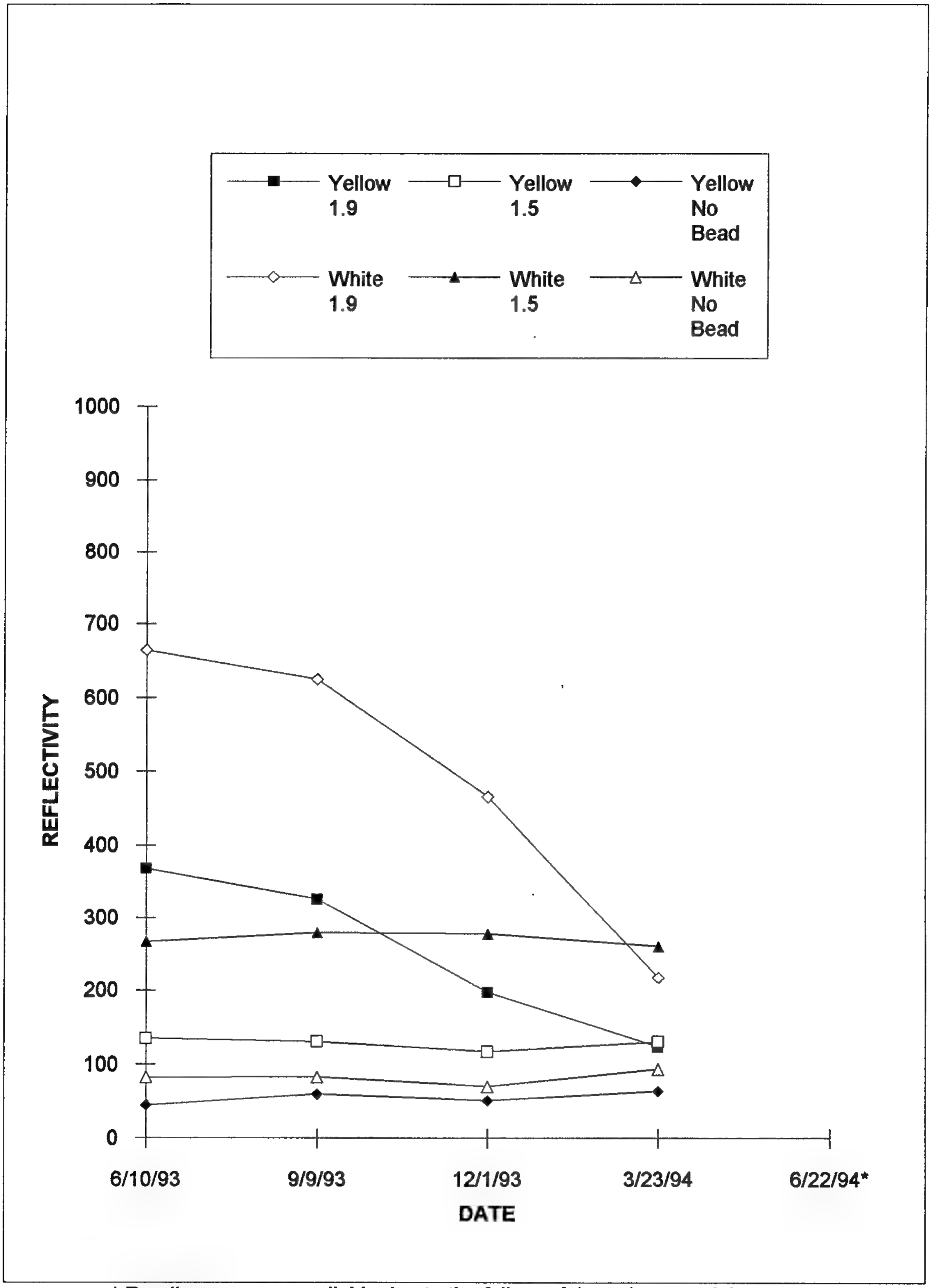


FIGURE A-18. ATLANTIC CITY - MORTON DURA-STRIPE - ASPHALT



* Readings were unavailable due to the failure of the paint material.

FIGURE A-19. PITTSBURGH - ADI/SAFEWAY - CONCRETE

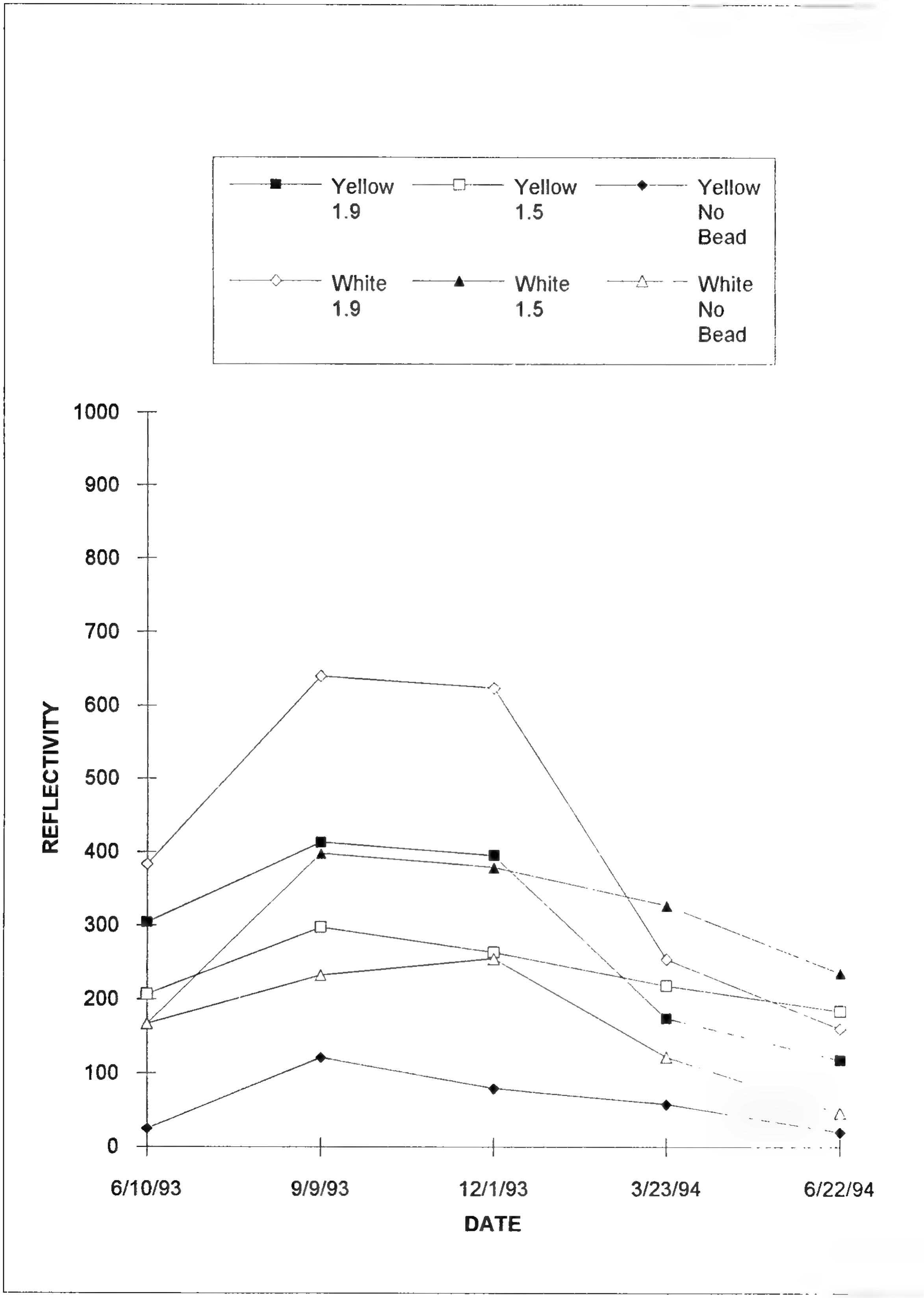
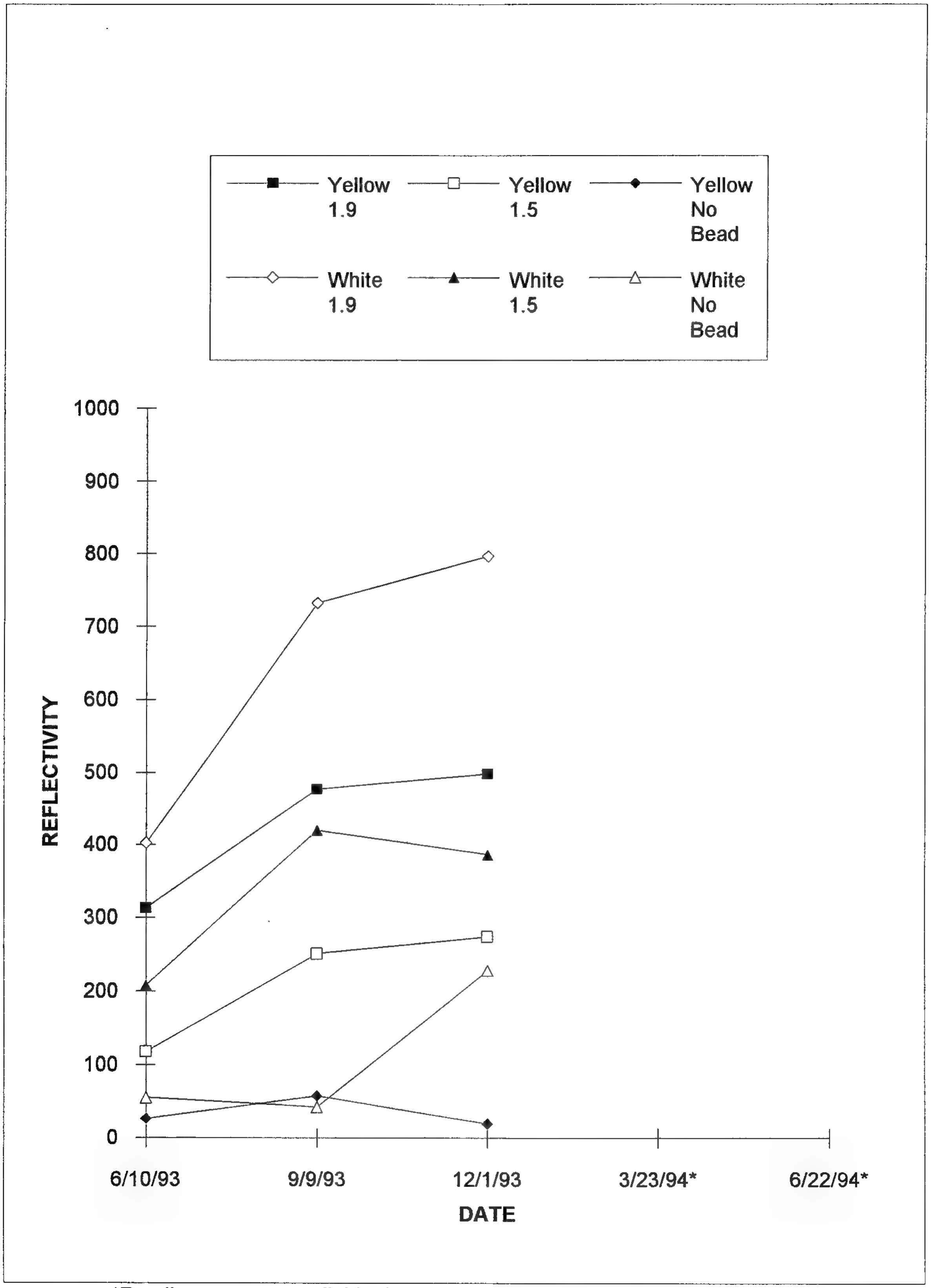
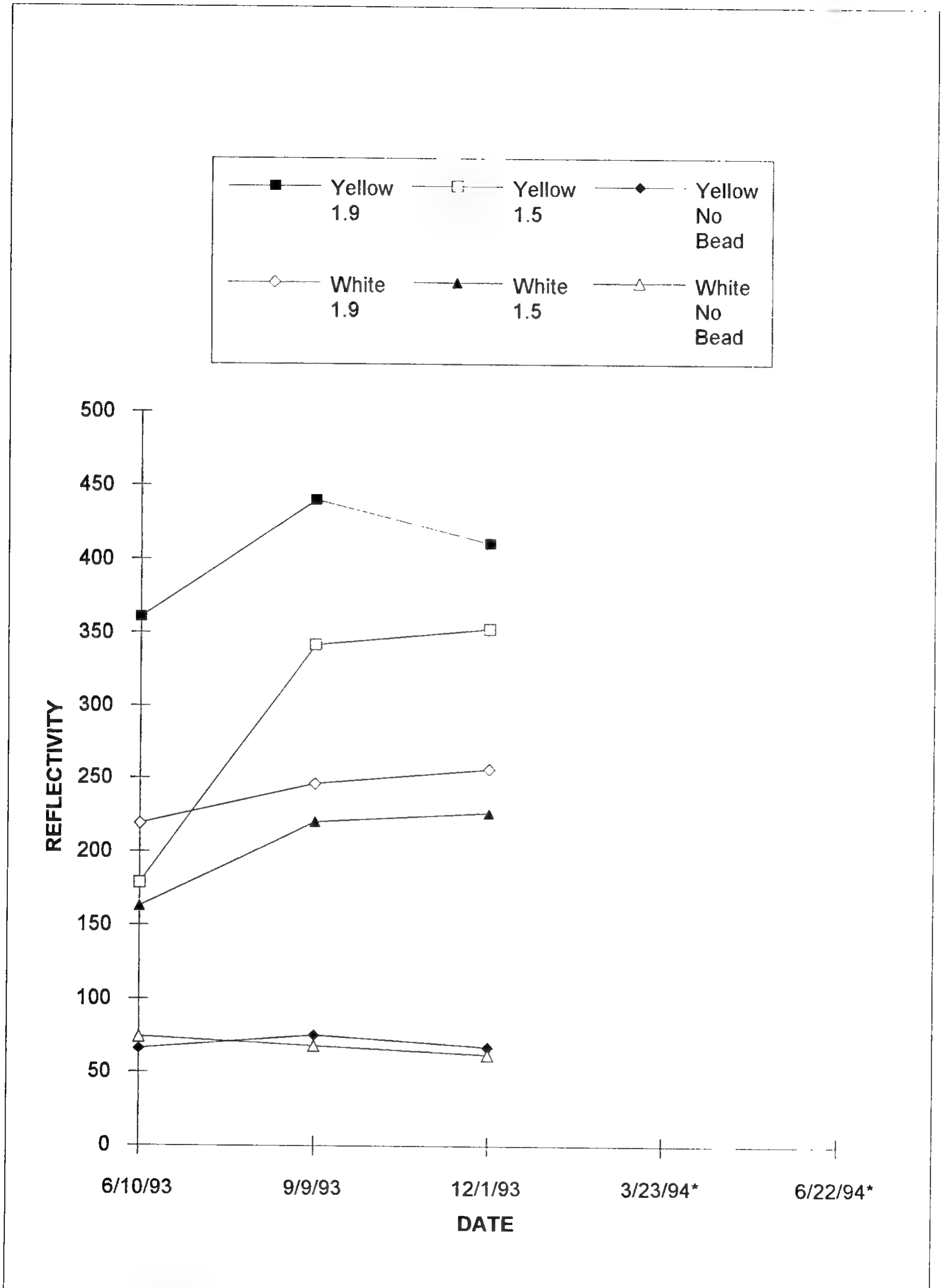


FIGURE A-20. PITTSBURGH - POLY-CARB - CONCRETE



*Readings were unavailable due to the failure of the paint material.

FIGURE A-21. PITTSBURGH - ROHM AND HAAS - CONCRETE



*Readings were unavailable due to the failure of the paint material.

FIGURE A-22. PITTSBURGH - MORTON DUROLINE - CONCRETE

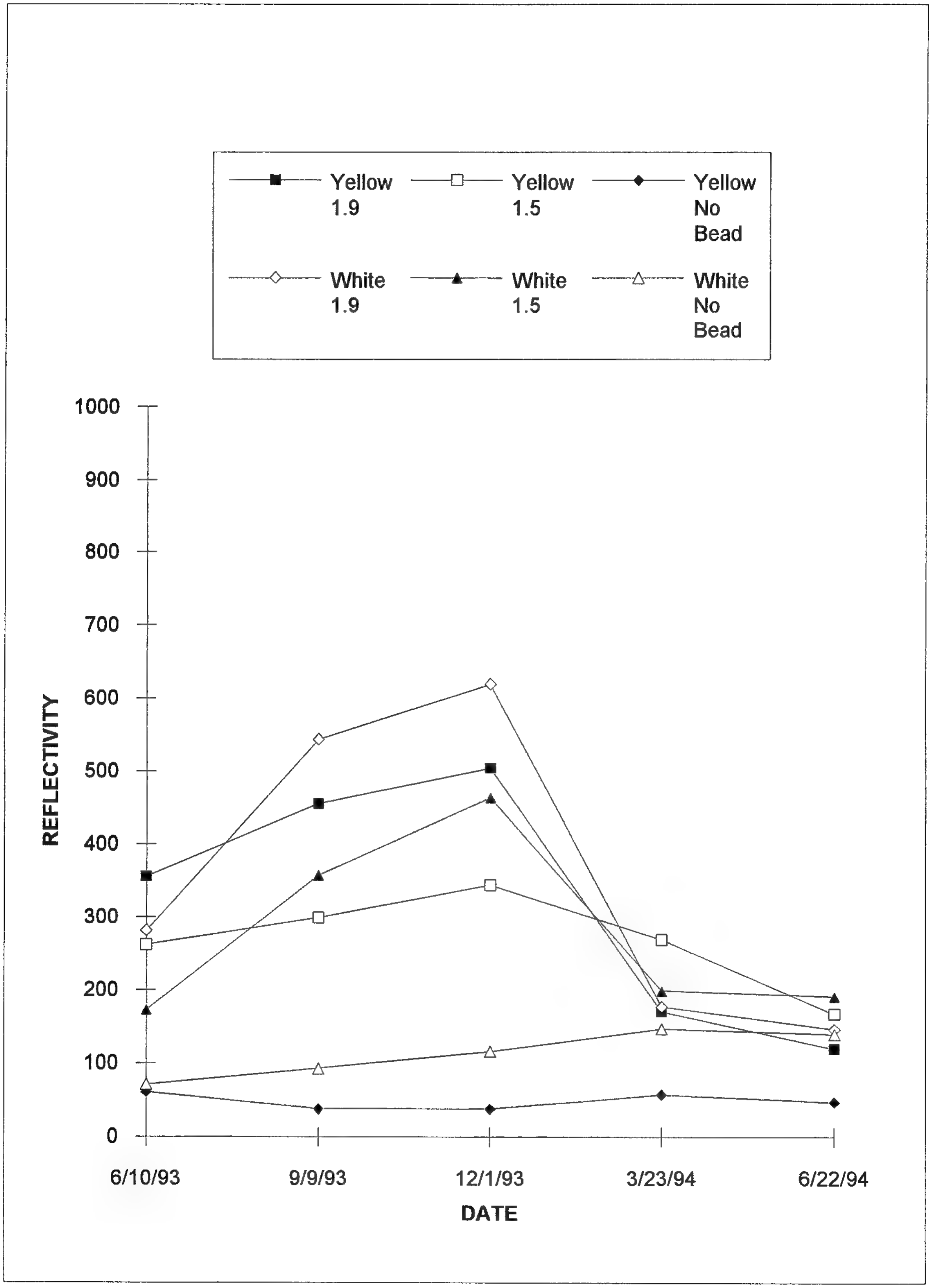


FIGURE A-23. PITTSBURGH - MORTON DURA-STRIPE - CONCRETE

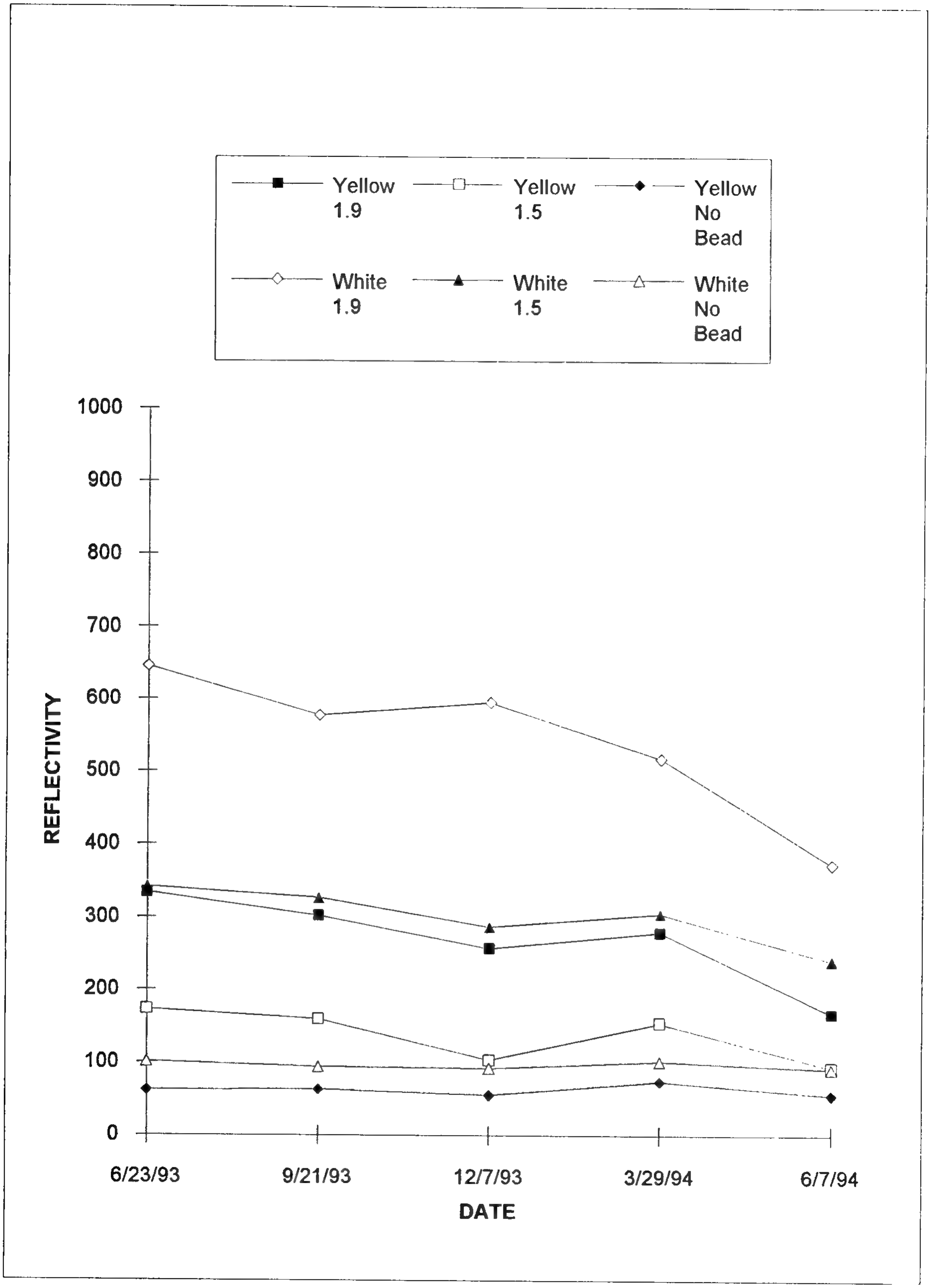


FIGURE A-24. PHOENIX - ADI/SAFEWAY - CONCRETE

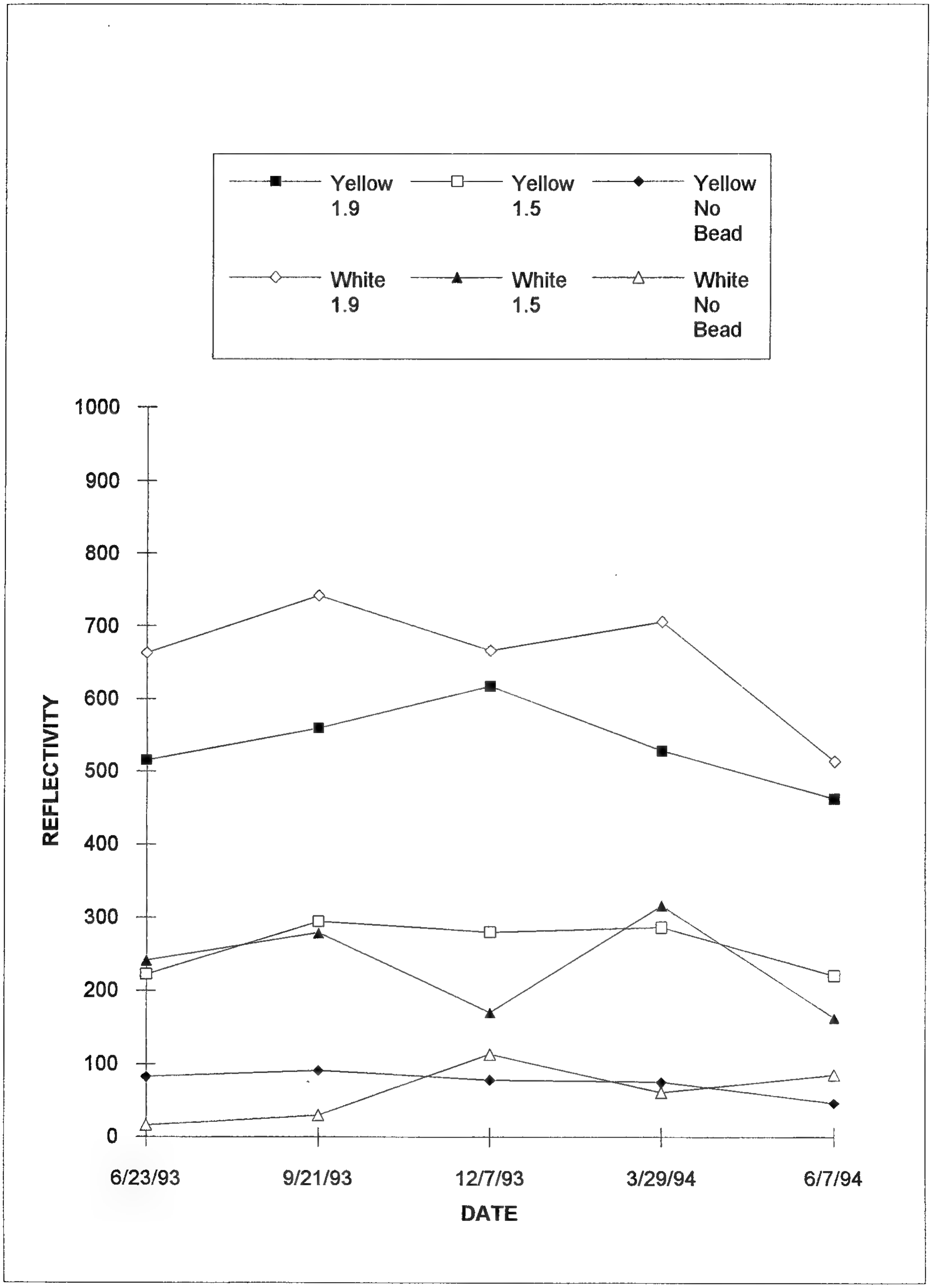


FIGURE A-25. PHOENIX - POLY-CARB - CONCRETE

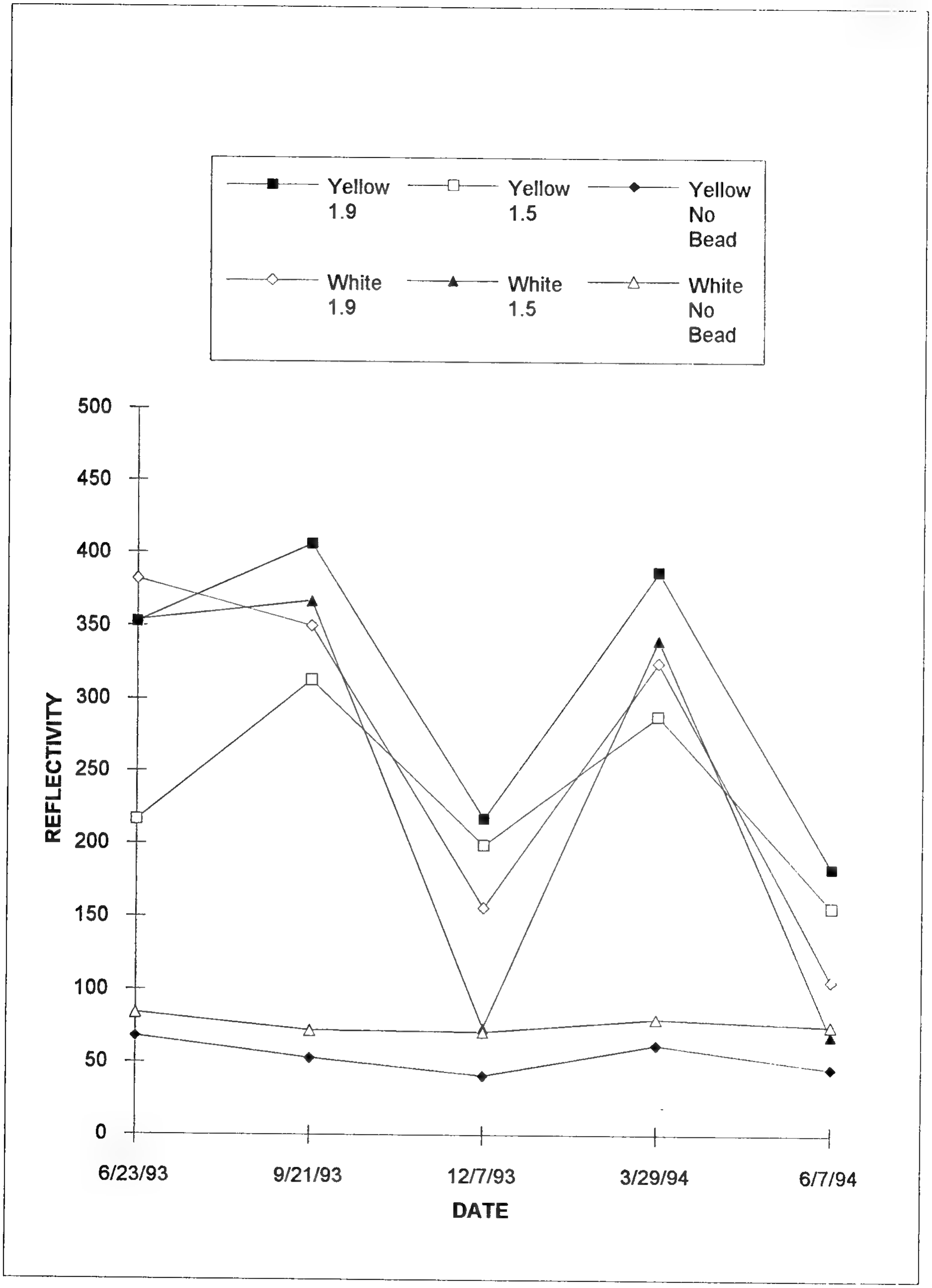


FIGURE A-26. PHOENIX - ROHM AND HAAS - CONCRETE

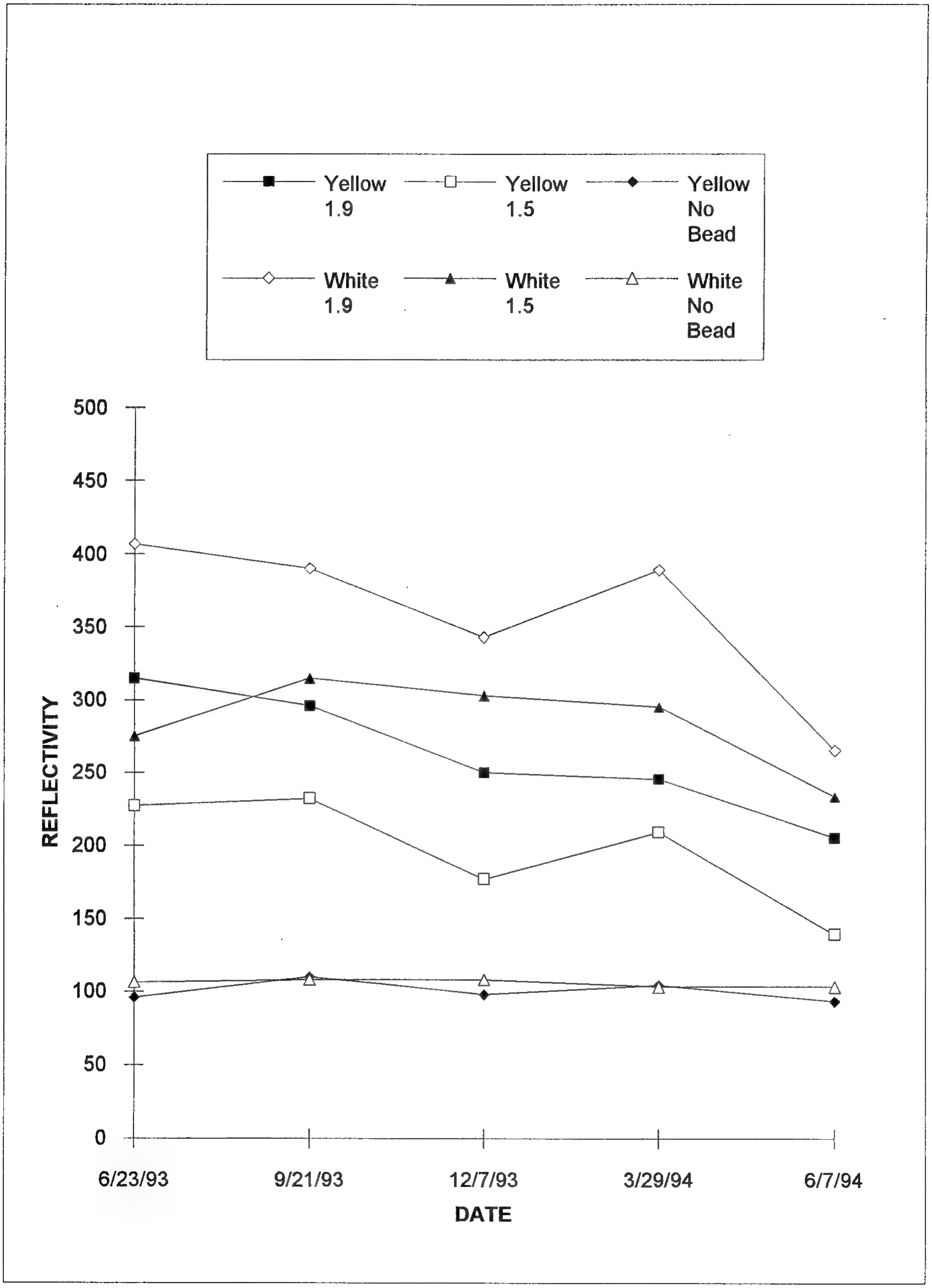


FIGURE A-27. PHOENIX - MORTON DUROLINE - CONCRETE

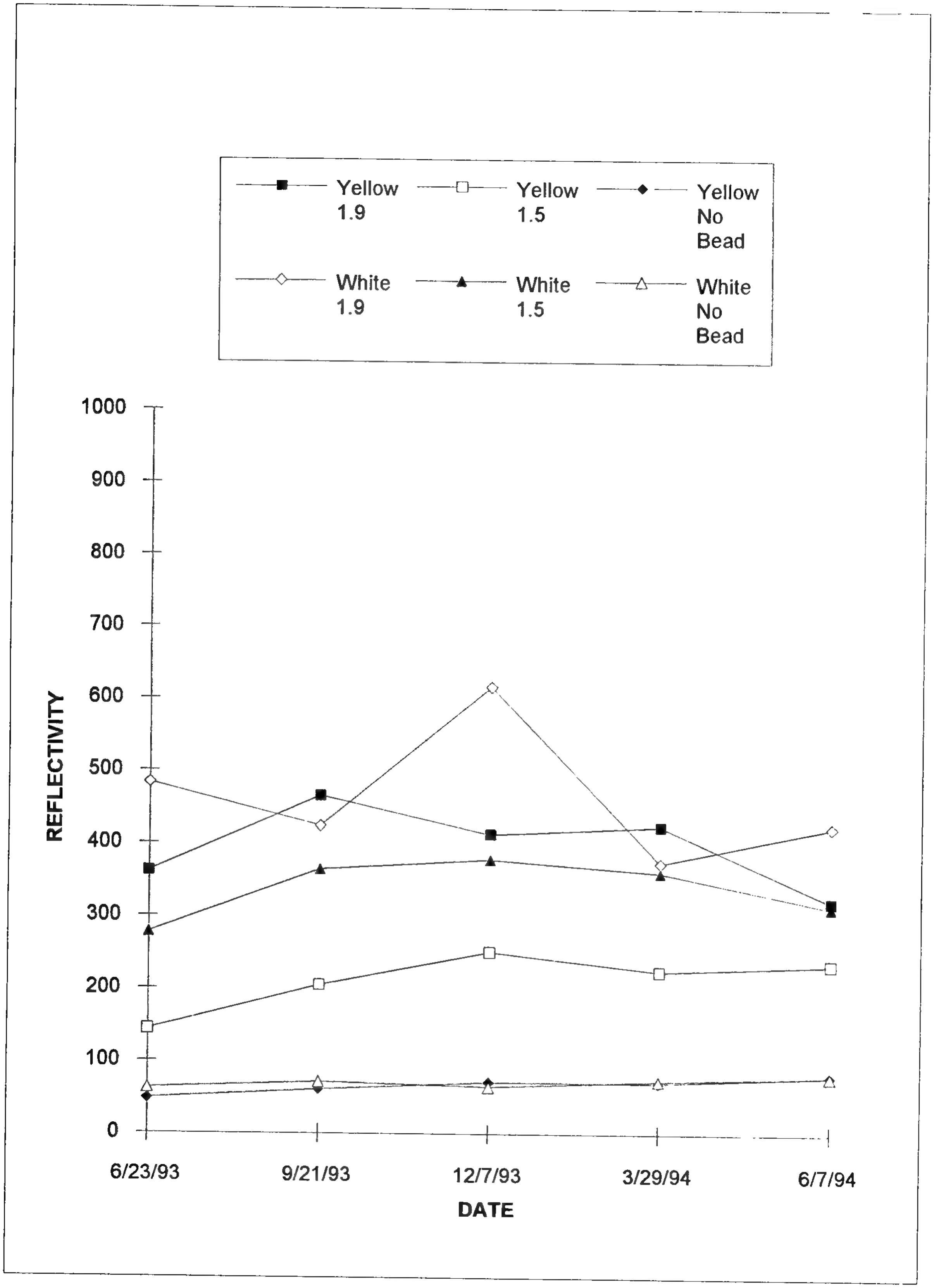


FIGURE A-28. PHOENIX - MORTON DURA-STRIPE - CONCRETE

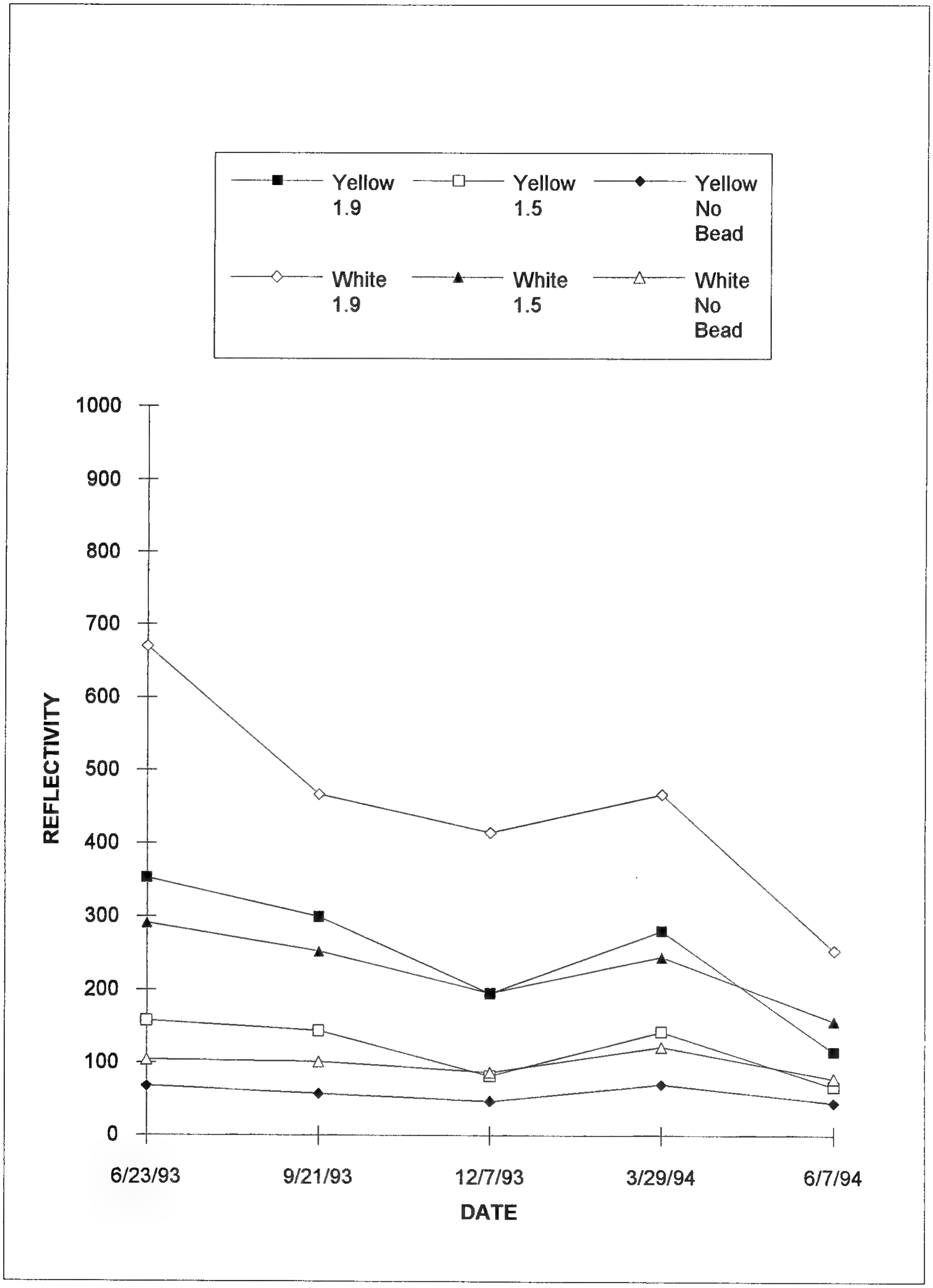


FIGURE A-29. PHOENIX - ADI/SAFEWAY - ASPHALT

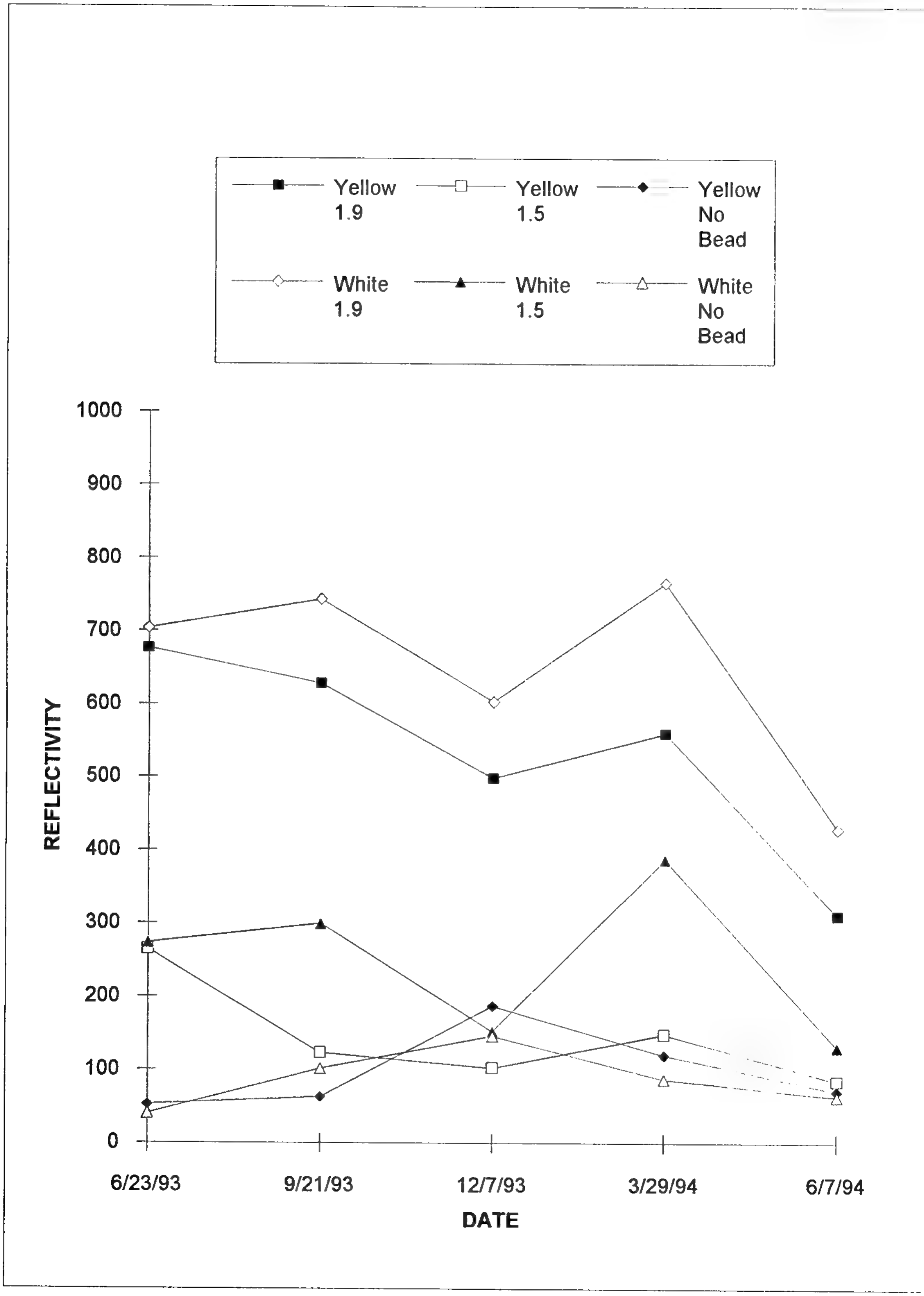


FIGURE A-30. PHOENIX - POLY-CARB - ASPHALT

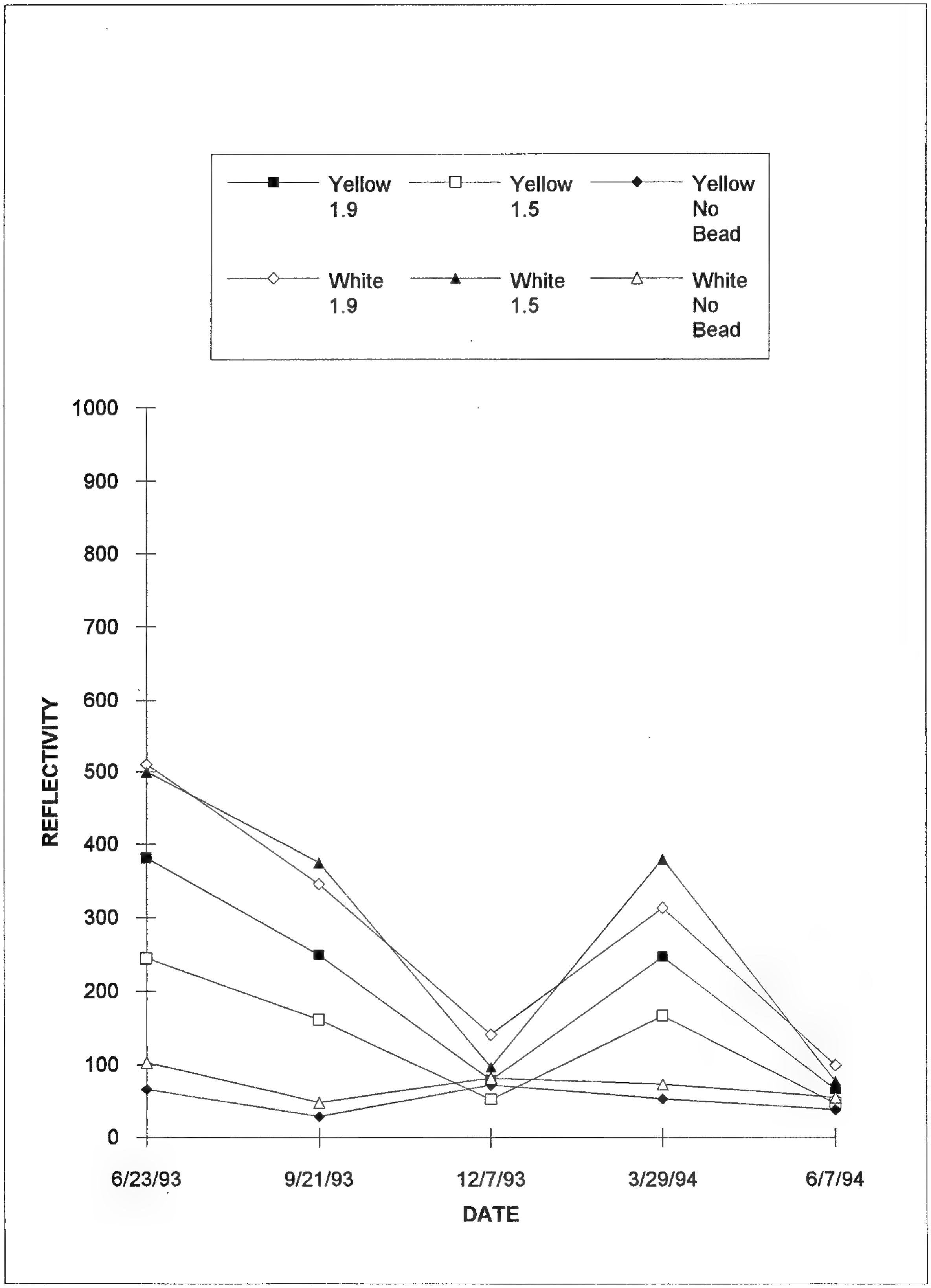


FIGURE A-31. PHOENIX - ROHM AND HAAS - ASPHALT

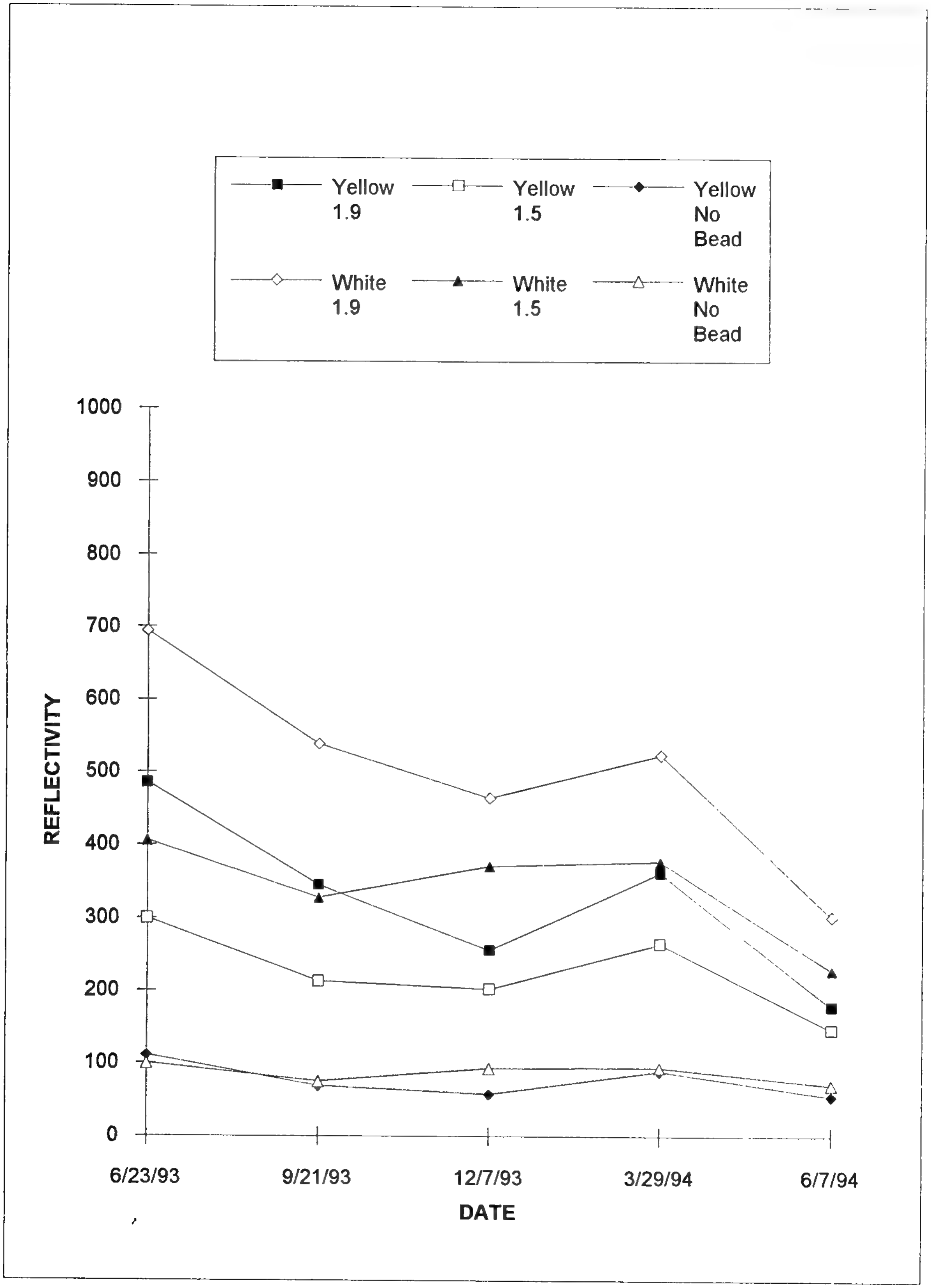


FIGURE A-32. PHOENIX - MORTON DUROLINE - ASPHALT

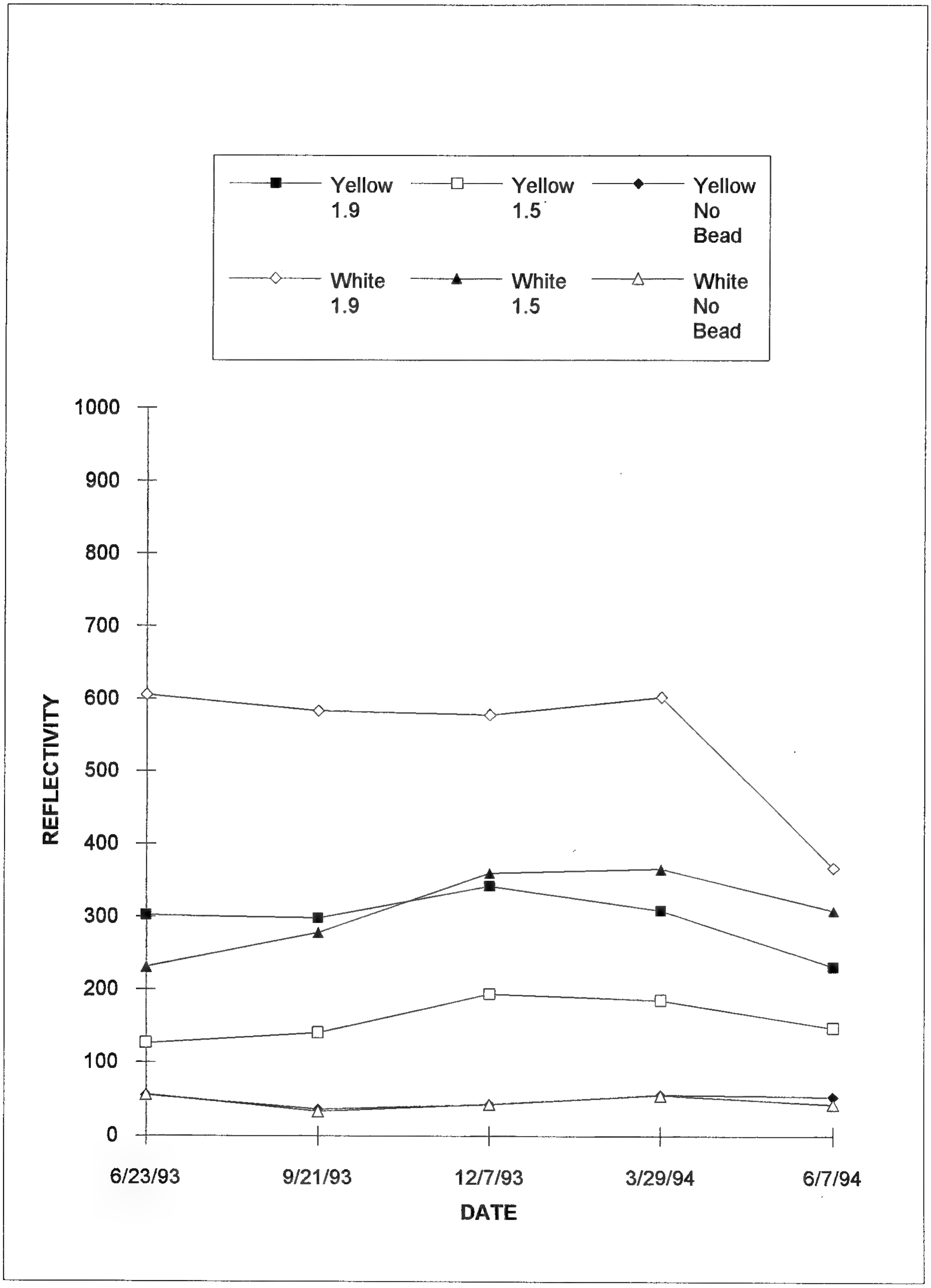


FIGURE A-33. PHOENIX - MORTON DURA-STRIPE - ASPHALT

Location: Atlantic City
Surface: Concrete

	5/26/93	7/6/93	7/29/93	8/26/93	9/30/93	10/29/93	11/24/93	12/20/93	1/24/94	3/15/94	3/31/94	5/3/94	5/23/94	6/1/94
ADI/Safeway														
Yellow 1.9	84	94	102	123	100	122	107	129	78	77	82	81	86	86
Yellow 1.5	89	92	100	96	83	92	83	102	74	90	94	95	100	101
Yellow 0	56	60	101	79	50	81	59	71	48	61	67	66	72	66
White 1.9	209	217	243	247	234	244	223	234	166	148	162	159	169	167
White 1.5	229	232	231	216	188	198	181	191	153	178	187	183	183	185
White 0	129	139	138	138	110	115	113	118	100	111	116	113	120	111
Poly-Carb														
Yellow 1.9	527	582	591	568	531	619	526	619	267	165	185	172	172	175
Yellow 1.5	198	250	276	267	269	277	248	280	237	233	229	234	236	228
Yellow 0	175	141	146	86	74	127	60	36	89	170	90	60	73	128
White 1.9	650	775	785	813	758	806	811	823	203	166	184	167	164	169
White 1.5	291	386	405	426	382	373	368	344	300	277	286	268	262	280
White 0	12	14	29	58	6	17	7	33	23	39	43	45	47	39
Rohm and Haas														
Yellow 1.9	329	318	301	294	288	282	251	281	97	64	73	56	59	60
Yellow 1.5	297	304	246	304	282	300	262	287	251	227	228	206	210	229
Yellow 0	38	25	33	33	23	28	21	32	28	44	36	35	50	29
White 1.9	721	937	922	904	854	868	803	844	284	191	188	163	159	171
White 1.5	380	473	485	464	408	425	403	438	429	478	472	448	446	455
White 0	53	42	42	54	35	38	32	42	41	78	48	56	53	56
Duroline														
Yellow 1.9	129	151	162	150	109	138	113	117	86	90	73	76	83	67
Yellow 1.5	160	132	112	132	95	108	102	91	89	103	84	88	73	85
Yellow 0	87	118	92	58	50	58	50	41	68	107	59	67	75	45
White 1.9	79	73	194	62	38	59	43	47	50	93	63	87	74	67
White 1.5	200	217	82	117	71	74	61	61	55	91	76	74	79	90
White 0	43	68	50	46	30	51	36	38	41	64	56	51	58	57
Dura-Stripe														
Yellow 1.9	365	441	452	429	388	415	358	398	64	69	58	60	65	57
Yellow 1.5	165	186	182	191	158	178	162	181	226	241	238	237	232	237
Yellow 0	78	78	94	82	59	79	59	61	68	62	63	64	64	63
White 1.9	376	454	520	416	420	368	420	511	184	158	142	137	148	143
White 1.5	214	246	258	272	245	261	236	289	186	174	165	160	163	166
White 0	73	87	92	96	86	93	83	106	100	111	109	110	114	112

FIGURE A-34. ATLANTIC CITY REFLECTIVITY MEASUREMENTS - CONCRETE

Location: Atlantic City
Surface: Asphalt

	5/26/93	7/6/93	7/29/93	8/26/93	9/30/93	10/29/93	11/24/93	12/20/93	1/24/94	3/15/94	3/31/94	5/3/94	5/23/94	6/1/94
ADI/Safeway														
Yellow 1.9	66	72	72	86	77	97	108	121	63	73	116	74	78	81
Yellow 1.5	107	117	117	110	93	108	103	100	78	94	96	98	104	103
Yellow 0	59	65	82	71	62	82	65	82	52	67	63	64	65	66
White 1.9	137	148	186	148	140	172	144	152	117	122	130	131	136	138
White 1.5	160	174	184	204	193	224	201	209	177	185	186	203	209	214
White 0	109	117	125	119	106	155	103	115	95	111	118	114	116	118
Poly-Carb														
Yellow 1.9	477	583	599	570	530	629	583	570	337	180	179	173	174	177
Yellow 1.5	235	286	303	295	276	302	252	245	213	194	196	194	195	199
Yellow 0	82	105	53	93	78	90	105	84	66	50	59	91	53	50
White 1.9	600	761	775	795	763	822	770	747	504	223	235	246	232	238
White 1.5	324	410	430	411	391	397	371	362	329	315	331	327	334	334
White 0	67	112	61	122	71	127	120	125	68	106	128	116	133	76
Rohm and Haas														
Yellow 1.9	387	360	360	430	399	402	384	399	285	163	158	156	142	148
Yellow 1.5	307	356	335	362	357	369	336	376	324	247	240	231	223	240
Yellow 0	66	62	60	54	47	57	45	57	50	56	57	53	50	54
White 1.9	665	702	698	872	772	794	759	734	591	269	293	276	263	259
White 1.5	441	449	468	428	422	448	407	418	361	238	243	234	227	226
White 0	103	90	88	83	73	94	87	83	76	72	75	72	78	73
Duroline														
Yellow 1.9	155	180	174	167	151	178	169	187	135	107	113	108	104	110
Yellow 1.5	142	147	160	180	173	205	180	199	176	127	134	124	121	127
Yellow 0	95	90	92	84	73	87	74	91	81	87	89	79	76	84
White 1.9	177	176	174	186	181	184	193	213	161	119	122	125	125	123
White 1.5	258	299	282	346	339	422	354	387	353	263	249	258	248	257
White 0	128	117	115	118	106	125	107	136	113	114	123	109	110	118
Dura-Stripe														
Yellow 1.9	221	307	322	339	326	352	327	363	331	188	199	182	171	170
Yellow 1.5	134	176	174	178	176	187	180	195	238	202	205	199	196	206
Yellow 0	49	56	55	65	55	59	53	65	69	69	69	65	64	68
White 1.9	261	357	350	485	467	514	485	533	242	130	141	133	132	141
White 1.5	174	222	215	184	155	176	138	160	129	150	162	157	150	167
White 0	65	94	99	107	100	109	102	123	124	139	154	140	142	157

FIGURE A-35. ATLANTIC CITY REFLECTIVITY MEASUREMENTS - ASPHALT

Location: Pittsburgh
Surface: Concrete

	6/10/93	9/9/93	12/1/93	3/23/94	6/22/94
ADI/ Safeway					
Yellow 1.9	368	326	197	124	*
Yellow 1.5	135	130	117	130	*
Yellow 0	45	60	51	64	*
White 1.9	664	625	466	218	*
White 1.5	267	279	278	261	*
White 0	82	83	70	94	*
Poly-Carb					
Yellow 1.9	304	413	395	174	118
Yellow 1.5	207	297	263	218	183
Yellow 0	25	121	79	58	20
White 1.9	383	640	624	254	160
White 1.5	167	398	379	327	235
White 0	167	232	255	122	46
Rohm and Haas					
Yellow 1.9	313	476	498	*	*
Yellow 1.5	118	251	274	*	*
Yellow 0	26	57	19	*	*
White 1.9	402	732	796	*	*
White 1.5	208	419	386	*	*
White 0	55	42	228	*	*
Duroline					
Yellow 1.9	361	440	411	*	*
Yellow 1.5	179	342	353	*	*
Yellow 0	66	75	67	*	*
White 1.9	219	246	256	*	*
White 1.5	163	220	226	*	*
White 0	74	68	62	*	*
Dura-Stripe					
Yellow 1.9	356	455	504	170	119
Yellow 1.5	262	299	344	269	167
Yellow 0	61	38	38	57	47
White 1.9	281	543	619	177	146
White 1.5	173	357	463	199	191
White 0	71	93	116	147	139

* Denotes readings were unobtainable due to the failure of the paint material.

FIGURE A-36. PITTSBURGH REFLECTIVITY MEASUREMENTS - CONCRETE

Location: Phoenix
Surface: Concrete

	6/23/93	9/21/93	12/7/93	3/29/94	6/7/94
ADI/Safeway					
Yellow 1.9	334	302	257	279	167
Yellow 1.5	173	159	103	154	93
Yellow 0	62	63	55	74	55
White 1.9	646	577	595	517	372
White 1.5	342	327	287	305	240
White 0	101	94	92	101	91
Poly-Carb					
Yellow 1.9	515	559	617	527	461
Yellow 1.5	222	294	280	286	220
Yellow 0	83	91	78	75	46
White 1.9	663	742	666	705	513
White 1.5	241	279	170	316	163
White 0	16	30	114	61	85
Rohm and Haas					
Yellow 1.9	353	406	217	387	183
Yellow 1.5	216	313	199	288	156
Yellow 0	68	53	41	62	46
White 1.9	382	350	156	325	106
White 1.5	354	367	74	341	69
White 0	84	72	71	80	75
Duroline					
Yellow 1.9	315	296	250	245	205
Yellow 1.5	227	232	177	209	139
Yellow 0	96	110	98	104	93
White 1.9	407	390	343	389	265
White 1.5	275	315	303	295	233
White 0	106	108	108	103	103
Dura-Stripe					
Yellow 1.9	362	465	412	423	320
Yellow 1.5	144	205	251	224	233
Yellow 0	48	61	71	70	80
White 1.9	483	424	616	373	422
White 1.5	278	364	378	360	312
White 0	63	71	65	73	79

FIGURE A-37. PHOENIX REFLECTIVITY MEASUREMENTS - CONCRETE

Location: Phoenix
Surface: Asphalt

	6/23/93	9/21/93	12/7/93	3/29/94	6/7/94
ADI/Safeway					
Yellow 1.9	353	299	195	280	115
Yellow 1.5	158	144	82	143	67
Yellow 0	68	57	47	70	45
White 1.9	670	466	414	466	253
White 1.5	291	252	196	245	157
White 0	104	101	87	122	78
Poly-Carb					
Yellow 1.9	676	628	498	559	310
Yellow 1.5	264	123	102	148	84
Yellow 0	52	63	187	120	70
White 1.9	704	743	603	766	428
White 1.5	273	299	152	387	131
White 0	40	101	146	87	63
Rohm and Haas					
Yellow 1.9	381	249	79	246	66
Yellow 1.5	245	161	52	166	47
Yellow 0	66	29	72	53	38
White 1.9	510	345	141	312	99
White 1.5	500	375	97	379	77
White 0	103	48	82	73	55
Duroline					
Yellow 1.9	485	345	256	362	178
Yellow 1.5	300	213	202	264	146
Yellow 0	111	69	58	89	55
White 1.9	694	538	464	523	302
White 1.5	406	328	371	377	228
White 0	100	75	93	94	70
Dura-Stripe					
Yellow 1.9	302	298	342	308	231
Yellow 1.5	126	140	194	185	147
Yellow 0	55	36	43	56	53
White 1.9	605	583	578	602	367
White 1.5	231	278	360	365	308
White 0	56	33	43	55	43

FIGURE A-38. PHOENIX REFLECTIVITY MEASUREMENTS - ASPHALT

SURFACE TYPE: CONCRETE

Location	Material	Color	1.9 IOR Glass Beads First Reading	1.9 IOR Glass Beads Last Reading	1.9 IOR Glass Beads % Change	1.5 IOR Glass Beads First Reading	1.5 IOR Glass Beads Last Reading	1.5 IOR Glass Beads % Change
ACY	ADI	Yel	84	86	2%	89	101	13%
		Wht	209	167	-20%	229	185	-19%
	P-C	Yel	527	175	-67%	198	228	15%
		Wht	650	169	-74%	291	280	-4%
	R-H	Yel	329	60	-82%	297	229	-23%
		Wht	721	171	-76%	380	455	20%
	DL	Yel	129	67	-48%	160	85	-47%
		Wht	79	67	-15%	200	90	-55%
	DS	Yel	365	57	-84%	165	237	44%
		Wht	376	143	-62%	214	166	-22%
PHX	ADI	Yel	334	167	-50%	173	93	-46%
		Wht	646	372	-42%	342	240	-30%
	P-C	Yel	515	416	-19%	222	220	-1%
		Wht	663	513	-23%	241	163	-32%
	R-H	Yel	353	183	-48%	216	156	-28%
		Wht	382	106	-72%	354	69	-81%
	DL	Yel	315	205	-35%	227	139	-39%
		Wht	407	265	-35%	275	233	-15%
	DS	Yel	362	320	-12%	144	233	62%
		Wht	483	422	-13%	278	312	12%
PIT	ADI	Yel	368	124*	-66%	135	130*	-4%
		Wht	664	218*	-67%	267	261*	-2%
	P-C	Yel	304	118	-61%	207	183	-12%
		Wht	383	160	-58%	167	235	41%
	R-H	Yel	313	498*	59%	118	274*	132%
		Wht	402	796*	98%	208	386*	86%
	DL	Yel	361	411*	14%	179	353*	97%
		Wht	219	256*	17%	163	226*	39%
	DS	Yel	356	119	-67%	262	167	-36%
		Wht	281	146	-48%	173	191	10%

* Denotes readings were unavailable due to the failure of the paint material.

FIGURE A-39. CHANGES IN REFLECTIVITY - CONCRETE

SURFACE TYPE: ASPHALT

Location	Material	Color	1.9 IOR Glass Beads First Reading	1.9 IOR Glass Beads Last Reading	1.9 IOR Glass Beads % Change	1.5 IOR Glass Beads First Reading	1.5 IOR Glass Beads Last Reading	1.5 IOR Glass Beads % Change
ACY	ADI	Yel	66	81	23%	107	103	-4%
		Wht	137	138	1%	160	214	34%
	P-C	Yel	477	177	-63%	235	199	-15%
		Wht	600	238	-60%	324	334	3%
	R-H	Yel	387	148	-62%	307	240	-22%
		Wht	665	259	-61%	441	226	-49%
	DL	Yel	155	110	-29%	142	127	-11%
		Wht	177	123	-31%	258	257	0%
	DS	Yel	221	170	-23%	134	206	54%
		Wht	261	141	-46%	174	167	-4%
PHX	ADI	Yel	353	115	-67%	158	67	-58%
		Wht	670	253	-62%	291	157	-46%
	P-C	Yel	676	310	-54%	264	84	-68%
		Wht	704	428	-39%	273	131	-52%
	R-H	Yel	381	66	-83%	245	47	-81%
		Wht	510	99	-81%	500	77	-85%
	DL	Yel	485	178	-63%	300	146	-51%
		Wht	694	302	-56%	406	228	-44%
	DS	Yel	302	231	-24%	126	147	17%
		Wht	605	367	-39%	231	308	33%

FIGURE A-40. CHANGES IN REFLECTIVITY - ASPHALT

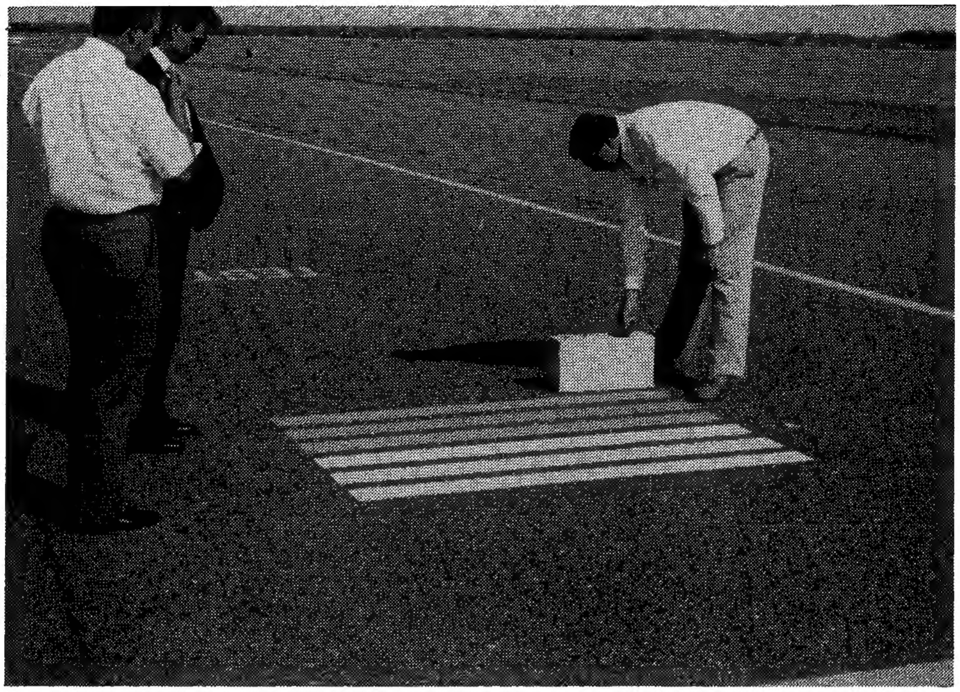


FIGURE A-41. CALIBRATING THE MIROLUX

FIGURE A-42. MEASURING RETRO-REFLECTIVITY

FIGURE A-43. LASER-LUX MOBILE RETRO-REFLECTOMETER

FIGURE A-44. FRICTION TESTING AT PITTSBURGH

STRIPE	MANUFACTURER	MATERIAL	BEADS	SILICA
7	Morton International - Dura-Stripe	Methacrylic Resin	1.9 IOR	Yes
6	Morton International - Dura-Stripe	Methacrylic Resin	1.5 IOR	Yes
5	Morton International - Dura-Stripe	Methacrylic Resin	None	Yes
4	Morton International - Duroline 2000	Water-borne Paint	None	Yes
3	Rohm and Hass	Water-borne Paint	None	No
2	Poly Carb - MK-55	Epoxy	None	No
1	ADI/Safeway - SafeGrip	Epoxy	None	Yes

FIGURE A-45. RUNWAY STRIPE MATERIAL COMPARISON - ATLANTIC CITY AND PITTSBURGH

PITTSBURGH

40 MPH

STRIPE	6/11/93	12/14/93	3/22/94	6/22/94
7	0.51	0.52	0.62	0.54
6	0.52	0.52	0.68	0.52
5	0.68	0.58	0.65	0.58
4	0.77	0.53	0.68	0.56
3	0.44	0.42	0.50	0.46
2	0.32	0.13	0.27	0.26
1	0.60	0.65	0.65	0.62

60 MPH

STRIPE	6/11/93	12/14/93	3/22/94	6/22/94
7	0.49	0.44	0.58	0.45
6	0.39	0.43	0.64	0.45
5	0.56	0.50	0.56	0.51
4	0.60	0.46	0.60	0.50
3	0.37	0.33	0.37	0.39
2	0.24	0.12	0.22	0.22
1	0.53	0.61	0.63	0.58

ATLANTIC CITY

40 MPH

STRIPE	5/27/93	9/15/93	12/2/93	5/11/94
7	0.42	0.43	0.42	0.59
6	0.51	0.36	0.44	0.52
5		0.37	0.47	0.52
4	0.99	0.86	0.88	0.89
3	0.47	0.43	0.48	0.54
2	0.40	0.37	0.32	0.30
1	0.90	0.90	0.95	0.89

60 MPH

STRIPE	5/27/93	9/15/93	12/2/93	5/11/94
7	0.35	0.31	0.33	0.44
6	0.31	0.27	0.26	0.40
5	0.37	0.27	0.32	0.42
4	0.86	0.72	0.75	0.78
3	0.39	0.38	0.37	0.47
2	0.32	0.27	0.26	0.25
1	0.75	0.80	0.86	0.77

* Averages of each run, wet, using the K.J. Law Runway Friction Tester

FIGURE A-46. FRICTION TEST RESULTS

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